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USSR Report

ENERGY

(FOUO 13/81)

Electrification of the Oil and Gas Industry of West Siberia

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ELECTRIFICATION OF THE OIL AND GAS INDUSTRY OF WEST SIBERIA

Moscow ELEKTRIFIKATSIYA NEFTYANOY I GAZOVOY PROMYSHLENNOSTI ZAPADNOY SIBIRI in Russian 1980 (signed to press 25 Nov 80) pp 1-153

[Annotation, introduction and chapters one through eight of the book by Yuriy Borisovich Novoselov, Viktor Petrovich Roslyakov and Vitaliy Alekseyevich Shpilevoy, Izdatel'stvo "Nedra", 1,660 copies, 182 pages, UDC [622.276+622.279]:620.9(571.1); chapters nine through eleven (pp 153-182) not translated by JPRS]

CONTENTS

ANNOTATION

[Text] Electrical power equipment, electrical power supply and control systems for drilling rigs, facilities for the extraction and field processing of oil, as well as compressor and pumping stations for oil fields and trunk petroleum and gas pipelines are briefly described in the book. Design calculations and operational methods are cited for the major electrical equipment, electrical networks, relay protection, grounding and lightning protection, taking into account the specific natural and climatic conditions of Western Siberia. Questions of the operational reliability of electrical power equipment are treated and recommendations are given for increasing the reliability. The experience with the development, introduction and operation of electrical equipment for the oil and gas industry of Western Siberia is reflected on a broad scale.

The book is intended for engineering and technical workers of oil and gas industry enterprises of Western Siberia and can be useful to all specialists involved with questions of the electrification of the oil and gas industry. Some 20 tables, 52 illustrations and 5 bibliographic citations.

Reviewer: Engineer V.D. Kudinov (Minstry of the Petroleum Industry).

Introduction

The discovery of the oil and gas bearing province in Western Siberia has for a long time governed the prospects for the development of the entire oil and gas industry of the Soviet Union. A fuel and power base, which plays an ever increasing role not just in the comprehensive development of this region, but also in the growth of the entire nation's productive forces, has been created and is successfully being developed in an unprecedentedly short time.

The decrees of the CPSU Central Committee and the USSR Council of Ministers provide for the development of the oil and gas industry of Western Siberia based on the latest achievements of science and engineering using the most modern techniques for the development of oil and gas fields as well as well drilling, with the widescale automation of all production processes.

The quite rapid growth in oil and gas extraction was assured by the priority given to the development of extremely large deposits with high output wells, an annual increase in the volumes and rates of drilling operations, the introduction of efficient systems for developing oil and gas fields, the widescale application of techniques for maintaining the formation rock pressure, as well as the industrialization of the processing units of fields, etc. From the very outset when the oil and gas industry came into being in Western Siberia, a course was taken towards the complete electrification and automation of all production processes [3]. Work began in this direction simultaneously with the extraction of the initial tons of Siberian oil. The most energy intensive consumers are the installations of the system for maintaining the rock formation pressure and the pumping stations for the trunk petroleum pipelines.

The possibility of utilizing series produced automation and electrification equipment in Western Sibierian conditions was ascertained in the initial stage of putting oil and gas fields in service. However, operational experience and research results demonstrated that for the reliable operation of automation hardware and electrical equipment in Western Siberian oil fields, it is essential to protect them against the effects of low temperatures.

There was not sufficient experience with the industrial operation of electrical power equipment under natural climatic conditions similar to the conditions of Western Siberia, and for this reason, the necessity arose for the formulation of a number of scientific research efforts, which would make it possible to determine the most efficient operational modes for electrical equipment, electrical power networks, as well ascertain their level of operational reliability.

The Western Siberian oil and gas bearing region is rather clearly and territorially demarcated into oil and gas provinces. The oil bearing regions are primarily located in the territory of the central portion of the Western Siberian lowlands, between the southern part of Siberia and the Far North; more precisely, in the area of the Central region near the Ob'. The gas bearing regions are located in the territory of the northern portion of Western Siberia and the Far North.

The natural climatic and geomorphological features of the Western Sibierian lowlands have generated a number of complex problems in the mastery of these regions. The relief of the regions is low-lying and very boggy. An exception is the natural elevations: the watersheds. The oil and gas deposits differ little from each other in terms of the lithographic characteristics. A difference is observed primarily in the thickness of the various deposits. The depth of occurrence of the detected productive strata is relatively shallow. For the regions near the Urals, the depths of wells runs to 1,400-1,800 m, for the Far North they are 800 to 1,400 m and for the Central Region near the Ob', 2,100 to 2,600 m. The considerable prospects in the Tyumenskaya oblast are related to the drilling of wells at a depth of more than 3,500 m. The drilling depths will not undergo any considerable changes during the upcoming decade. In 1980, the average drilling depth will amount to 2,810 m for geological prospecting wells and 2,480 m for operational ones.

In terms of the nature of the relief and landscape features, the regions under consideration are a component part of the enormous erosion aggradation Western Siberian lowlands. The specific features of the relief are due to the slight amount of altitude by which the extensive cup-shaped lowlands exceed sea level and the small degree of drainage of the entire territory. The hydrographic network of the territory of the Central Region near Ob' is represented by numerous lakes, water courses, oxbow-lakes, microlakes, boggy rivers, streams and a boggy group of marshes.

The majority of the oil deposits of the Central Region near the Ob' are located in the flood-plain of the Ob' river. Great summer floods are characteristic of the Ob', where the high water floods enormous spaces. The duration of the high flood waters runs up to two months. The climate of the Central Region near the Ob' is sharply continental: it is characterized by a short, relatively hot summer (the maximum air temperature in July is +35 °C) and an extended freezing winter (the minimum air temperature is -55 °C). The frost free period averages 100 to 150 days. The average air temperature over several years for the coldest month (January) is -22 °C, and for the hottest (July), is +19 °C; the average annual relative air humidity amounts to 76 percent.

In terms of the intensity of the ice crust--hoar frost deposits, the central region near the Ob' belongs to region I; and in terms of the wind, it belongs to region II. The average annual amount of precipitation is 400 to 500 mm where the bulk of it (47 to 48 percent) falls during the warm season of the year (July-August). The abundance of precipitation and the poor evaporation create favorable conditions for the formation of bogs and lakes.

Winter in the region is snowy. The thickness of the snow cover reaches a maximum in March and amounts to 30 to 90 cm. A stable snow cover is formed by the end of October and lasts for an average of 190-230 days.

The Central Region Near the Ob', within the system of permafrost temperature regionalization of the territory of the USSR, is located in the region of seasonal feezing of the soil, which starts in October-November and reaches a maximum in March-April. The depth of freezing amounts to 0.2-0.6 m in the peaty water saturated soils, 1.2-2.5 m in sandy loams and loamy clays, and 2.6-3.6 m in sands. The mastery of the oil and gas bearing regions of Western Siberia entails considerable difficulties and expenditures, which are governed by the rapid pace of oil and gas extraction as well as the special natural, geographical and economic conditions. Sonsiderable density of the deposits, a comparatively shallow depth of occurrence of the oil and gas bearing strata, easy drillability of the rock, high yields of the wells, the possibility of long term gusher operation as well as the high quality of the oil with a moderate paraffin content and the absence of salts and sulfur are characteristic of the region.

The bogginess and flooding of the territory of the oil fields with snow melt flooding are responsible for the widescale application of group drilling of the wells and the seasonal moving of the drilling rigs. The arrangement of the wells in groups reduces the cost of the foundations for drilling, of the well servicing and the processing equipment, as well as the expenditures for the oil and gas collection and transportation system.

A substantial curtailment of capital and operational expenditures under local conditions is achieved by colocating the sites of oil field facilities. In oil fields, this means the combining of group metering installations (GZU), supplemental pressure pumping stations (DNS), group pumping stations (KNS), comprehensive oil preparation installations (UKPN) and transformer substation. In gas fields, this means the combining of comprehensive gas preparation installations (UKPG), compressor stations (KS) and transformer substations, as well as combining the routes for the gas field conduits: pipes, oil pipelines, gas pipelines, water lines, power transmission, remote control and communications lines and roads.

Industrial construction methods have found widescale application under the difficult conditions of construction of oil field facilities and oil and gas transportation facilities in boggy territories. Series plant fabrication of modular complete installation packages has been organized and set up, which makes it possible to reduce the construction and installation work to a minimum at the construction sites. In this case, the construction cost and the timeframe for placing facilities in service are significanly reduced.

The natrual climatic conditions of Western Siberia and the great bogginess of the oil and gas field territory have had a substantial impact on the resolution of the problems of electrification for these regions: the selection of the circuit variants for the external electric power supply, the structural designs for power transmission lines and substations; the choice of the types of electrical power equipment, power generation sets and electrical materials used in electrical installations.

All of the electrical hardware and power equipment, installed in the open or in modules made of metal channels, experience the influence of the severe climatic conditions one way or another. The frequently repeating extreme meteorological phenomona have a special impact on the operability of electrical power equipment: frequent temperature transitions through 0 °C, sharp temperature drops, the combination of low temperatures and strong winds, extended periods of rain and bad road conditions, fogs, etc.

Increased requirements are placed on electrical equipment set up in the open. Such equipment includes electric motors for pumping jacks, oil pumps and drilling rigs, power transformers at various capacities and voltages, substation equipment, etc.

The design of economically efficient electrical power supply systems and components for oil field electrical equipment under cold climatic conditions depends on how completely the specific operational features are successively taken into account and the determination of the most efficient approaches to increasing the reliability of electrical equipment.

CHAPTER ONE. ELECTRICAL POWER ENGINEERING AND THE EXTERNAL ELECTRIC POWER SUPPLY

General Information and the Basic Construction Principles for an Electric Power Supply System

The beginning of the electrification of the oil and gas industry of Western Siberia entailed considerable difficulties caused by the great remotemeness of the oil and gas deposits from power generation centers and the networks of the state power system. The nearest electric power station, the Tyumenskaya TETs with a capacity of 150 MW was located 400 to 1,000 km from the oil deposits and 1,500 to 2,000 km from the gas deposits.

It was necessary to start the organization of the electrical power supply for oil extraction facilities, the industrial base and oil worker settlements with the installation of independent electric power stations. The first such sources were diesel electric power stations with generators having a capacity of from 50 to 200 KW. By the end of 1965, 10 such electric power stations with an overall capacity of 1,615 KW were installed in the oil extraction regions. In October of 1966, the first stage of a permanent diesel electric power station as a part of three plants with a capacity of 630 KW each was placed in service in tne Megionneft' adminstration in Nizhnevartovsk. At the beginning of the next year, its capacity reached 3,150 KW. Similar electric power stations were also built in Surgut and the Strezhevoy and Poykovskiy settlements.

Electrical power engineering for the petroleum extracting province developed in accordance with a two stage plan. The first stage encompassed the period up to the connection to the state power system; the second stage encompassed the period after connection to the system. The electrical loads of oil fields (oil pumping plants, group pumping stations for the rock formation pressure maintenance system, electrical drive drilling, mechanized oil extraction wells) required temporary, but pwerful electrical power sources in the initial stage. Steam-turbine power trains of the B-4000 and Ch-2500 types with capacities of 4,000 and 2,500 KW respectively, which ran on crude unrefined oil or on byproduct natural gas came to be used as such sources.

The power trains played their own positive part, however, the further increasing of generator capacities by the additional installation of power trains was not expedient because of the duration of their transportation and construction.

In the beginning of 1967, industrial tests of two gas turbine electric power station units were started: the PEG-1000-6300 and PEG-1250-6300. An AI-20 gas turbine aviation engine, which had run out its service life was used as the drive, with a few structural modifications. Thereafter, these stations came to be produced in transportable designs. In 1969, six transportable gas turbine PAES-1600-T/6.3 electric power stations were placed in service. The transportable electric power stations do not require construction of special buildings for the installation, are equipped with more sophisticated automation and can operate in parallel with each other and with the power system. By the end of 1971. two PAES-2500-T/6.3 and fifteen PAES-1600-T/6.3 electric power stations were in service in the oil regions of Western Siberia.

The preparatory work for the second stage of power engineering development for the oil extracting region of Western Siberia was started simultaneously with the realization of the first stage program. Schemes were developed for the electrical power supply to the fields, cities and settlements in which the primary electric power source was the Tyumenskaya TETs, the capacity of which had to be increased from 150 to 450 MW. The station was tied into the Urals power grid with two 110 KV power transmission lines 400 and 300 km long. In accordance with the circuit configuration which was developed, the construction of the following was planned: a 500 KV Tyumen'--Ust'-Balyk--Surgut power transmission line (with its temporary use at a voltage of 220 KV), a 220 KV Surgut--Megion power transmission line, a 220 KV Tyumen'--Tavda transmission line and 110 KV Tavda--Uray power transmission line.

The construction of the Surgutskaya GRES was started in 1968, for which byproduct natural gas was used as the fuel. The first unit with a capacity of 200 MW was brought on line at the end of 1972. The total planned capacity of the GRES is 2,544 MW. By this time, a scheme had been developed for the electrical power supply to the oil and gas deposits of Western Siberia, which was the basis for the overall power engineering construction in the subsequent period.

Deep entrances were used for the high voltages going into the load centers to supply electrical power to the oil fields. The 110/6 and 35/6 KV transformer substations were colocated with the production process facilities: the group pumping stations, the oil collection points, gas compressor stations, water intake facilities, etc. With the mechanized extraction of oil, a provision was made in each well for the installation of separate transformer points; in the case of group drilling, there should be such a point in each group.

Special attention was devoted to assuring the operational reliability of open wire lines and substations, since under conditions where there are not roads, the failure of 35 and 110 KV lines or the transformer of a dead-end substation could lead to a long shutdown of the users. For this reason, the decision was made to use only two-circuit lines at a voltage of 110 or 35 KV, and to construct radial 6 KV electric power transmission lines, connected in a ring by means of switching apparatus from various substations. The increase in reliability was achieved also through the use of dual transformer substations (in case of an emergency with one of the transformers, the feed of electrical power could be limited to some consumers, without disconnecting specially important production facilities).

The major source of electrical power for the oil regions of Western Siberia during 1969-1972 was the Tyumenskaya TETs, and since 1973, the Surgutskaya GRES. At the beginning of 1973, the 500 KV Reftinskaya GRES--Tyumen' power transmission line was placed in service, which made it possible to obtain electrical power from the integrated Urals power grid. At the present time, the Tyumenskaya TETs and the Urals power grid are back-up electrical power supply sources.

The dynamics of the growth in the electrical load of the oil industry of Western Siberia and the capacities of Surgut electric power station is shown in Figure 1.

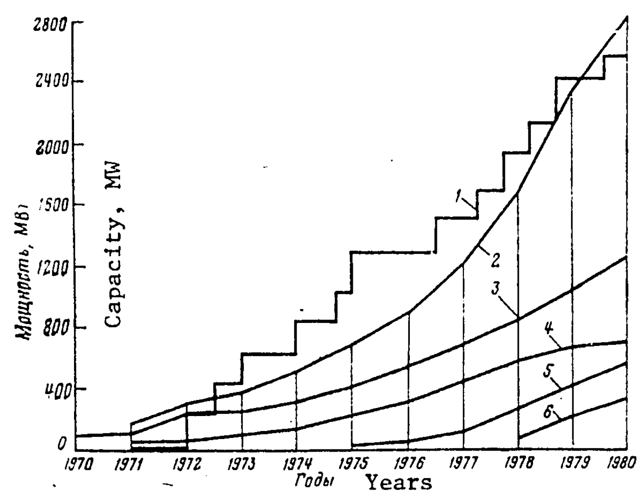

Figure 1. The dynamics of the electrical loads of the oil and gas industry of Western Siberia and the capacity of Surgut electric power station.

Key: 1. Capacity of the electric power station;
2. Overall loads;
3. Loads of the Glavtyumenneftegaz [Main Tyumen' Oil and Gas Administration];
4. Loads of the Major trunk oil pipeline administration;
5. Loads of the gas works;
6. Loads of Tyumengazprom [Tyumen' Gas Industry].

The electrical loads and electrical power consumption in 1980 are estimated at 2,800 MW and 14 billion KWH respectively for Western Siberia as a whole and will increase by a factor of four as compared to 1975 while petroleum extraction doubles and gas extraction triples.

Such a swift growth in the electrical load is explained not only by the increase in the absolute volume of oil extraction, but also by the following factors:

--An increase in the volume of water being pumped, referenced per one ton of extracted oil;

--A significant growth in the number of oil wells being operated with submersible deep well pumps for oil extraction;

--A significant increase in the percentage of operational drilling using electrical drives (up to 90-95 percent);

--An increase in the quantity of liquid extracted because of a rise in the water content of the oil;

--The transition to surface water supply sources for the systems to maintain rock formation pressure in place of underground (Cenomanian) waters;

--A significant rise (by a factor of 1.52) in the pressure in rock formation pressure maintenance systems;

--The great remoteness of new deposits from existing major communications lines;

--An increase in the volumes of oil preparation and a number of other factors.

It is proposed that the 500/220/110 KV substation in the region of Urengoy be used as the major electrical power supply source for the oil regions of the northern Tyumenskaya oblast. It will also be the major one for the enterprises of the gas extraction industry and the entire adjacent region. The substation will be powered via a 500 KV power transmission line from the Surgutskaya GRES.

At new oil and gas deposits, gas turbine and diesel electric power stations are being used as the electric power sources until electrical power is supplied from the power system.

Electrical power supply configurations using deep entrances for voltages of 6.35 or 110 KV and the subdividing of substations in all stages were taken as the basis for the electrical power supply to the oil extracting enterprises of Western Siberia. The subdivided substations with deep entrances replace the previously used intermediate distribution points. In this case, an intermediate switching stage is eliminated, something which is the great advantage of the adopted power supply system. In the case of deep entrances and high capacity current conductors, the length of the 6 and 10 KV network is sharply curtailed in the initial power supply stage and its reliability is significantly improved.

Where deep entrance substations are present which are broken up into smaller units, areas of outages are curtailed, switchgear design is simplified since the working currents and short currents at the secondary voltage are reduced, the energy losses are reduced, voltage regulation is facilitated and the expansion of the electrical power supply system is simplified.

Questions of the electrical power supply are resolved in a comprehensive manner together with construction and production process questions. A characteristic example is the circuit for the electric power supply to the Samotlor oil field [2].

The territory of the deposit is almost solidly covered with peaty bogs and lakes. The production process facilities for petroleum extraction (group pumping stations for pumping water into the rock formation, the output pumping stations for pumping out the oil, the central product depots) are bulk filled sites. The electrical loads for one site run up to 50 MW. A deep entrance 110/6 or 110/35/6 KV substation is set up at each site. Standard production process units have been developed for the Samotlorskiy oil field which contain all of the requisite electrical, power and production process conduits.

The use of 6 KV voltage conductors instead of cable lines has a significant economic impact on the distribution of power within a facility when transmitting large power levels from a 110/6 KV substation. A flexible current conductor with intraphase transposition of the conductors has a comparatively low inductive reactance (0.121 ohms/km). The conductors are strung by means of the fittings for open wire power transmission lines.

As a rule, the installation of two transformers with separate operation on the 6 KV side is the plan at substations; a single system of buses sectionalized into two or more sections is provided in the 6 KV distribution switchgear. The transformers are usually powered from the 110 KV side with the installation of jumpers with isolating switches at the substation.

Rapidly installable KTPB 110 KV complete substation packages produced by the Kuybyshev "Elektroshchit" plant with short circuiting devices and isolators on the 110 KV side have found widescale application at Samotlor. Substations made by the same plant with oil switches on the 35 KV side are widely used at a voltage of 35 KV.

The substation is built on a modular principle, working from the separate operation of its components. In this case, sufficient supply reliability is assured through the use of automation.

The compactness of modular substations promotes the successfully introduction of deep entrances. Deep entrance substations are fed via trunk or radial two-circuit open wire electrical power transmission lines.

The widescale use of large modular complete device packages of all kinds and at all voltage levels, as well as the mobility of the electrical installations are promoting a reduction in the timeframe for electrical installation work, curtailing the project plan documentation and provide for rapid interchangeability of the components of electrical installations.

Dispatcher control is provided for complex electrical power supply systems for large oil extraction enterprises and automated systems are used to control the electrical power system for the enterprises. The introduction of automated control systems, outfitted with computer equipment and sophisticated data retrieval and processing hardware, promotes the stepping-up of production and the making of optimal decisions under the complex operational conditions of a modern industrial enterprise.

The External Electric Power Supply for Oil and Gas Deposits

The carrying capacity of the Tyumen'--Surgut electric power transmission line with a length of 720 km amounts to 200 MW when operated at 220 KV; when operated at 500 KV, it 1,000 MW. The route of the line was chosen along the Tyumen'---Tobol'sk section, along the existing automobile highway; it was chosen along the route of the Ust'-Balyk--Omsk oil pipeline on the Tobol'sk--Dem'yansk section. The power line crosses nine navigable rivers, including the Irtych, Tobol, Yuganskaya Ob' and the Ob' rivers.

The substations of oil pumping stations (NPS) of the Ust'-Balyak--Omsk oil pipeline at the following voltages are connected to this power transmission line:

--220/35/6 KV at the "Dem'yanskaya" with 2 x 63 MVA transformers; the substations powering the "Mugen" and "Uvat" oil pumping stations are connected to the "Dem'yanskaya" substation via a 220 KV two-circuit power transmission line;

--220/110/6 KV at the "Salym" with 2 x 30 MVA transformers; the loads of the "Salym" oil pumping stations are fed from the substation at a voltage of 6 KV; power is fed via a two-circuit 110 KV power transmission line from the "Salym" substation to the 110 KV substation for the "Yuzhnyy Balyk" oil pumping station and to the Mamontovskiy and Pravdinskiy oil fields;

--220/110/6 KV at "Karkateyevo" with 2 x 20 and 1 x 32 MVA transformers, from which the loads of the Karkateyevo" oil pumping station are powered at a voltage of 6 KV;

--220/35/6 KV at "Ust'-Balyk" with 3x40 MVA transformers; the consumers of the Ust'-Balyk oil field and the city of the Nefteyugansk are supplied from the substation at a voltage of 35 KV;

--220/110/10 KV at the "Surgut" with 2x125 MVA autotransformers; the Western-Surgut, Fedorov and Solkinsk oil fields as well as the city of the Surgut are supplied with electrical power from the substation via a 110 KV power transmission line.

The "Yuzhnyy Balyk" substation was placed in service in 1974. This substation supplies electrical power to the "Salym" and "Yuzhnyy Balyk" oil pumping stations of the Mamontovskiy and Pravdinskiy oil fields. In 1974, the "Irtysh" 500/110/10 KV substation with autotransformers of 250 MVA each was placed in service in the region of Tobol'sk. The "Irtysh" substation supplied the electrical power to the "Aremzyany" oil pumping station as well as the "Vagay","Novo-Petrovskoye" oil pumping stations and the city of Tobolsk.

The 500 KV "Yuzhnyy Balyk" ("Magistral'naya") substation was placed in service in 1975, while the Dem'yanskaya--Yuzhnyy Balyk power transmission line section was changed over to a voltage of 500 KV. In the same year, the Surgutskaya GRES---"Magistralnaya" power transmission line section was later changed over to a voltage of 500 KV also. With this, the "Karkateyevo" oil pumping station and the Ust'-Balyk oil field with the city of Nefteyugansk were connected to the newly constructed single-circuit 220 KV Magistral'naya--Karkateyevo--Ust'-Balyk power transmission line.

The dynamics of the growth in the electrical loads of the oil fields powered from the Tyumen'--Surgut high voltage line are shown in Table 1.

Electrical power is supplied to the Mamontovskoye field from the "Mamontovskaya" 110/35/6 KV substation with two transformers of 16 MVA each. The electrical power is distributed via 35 KV lines to five 35/6 KV transformer substations with an overall installed transformer capacity of 40 MVA.

The 110/35/6 KV "Mamontovskaya 2" substation with 2x40 MVA transformers was placed in service in 1976 to provide electrical power to the central oil collection point of the Mamontovskoye field and to supply electrical power to the southern portion of the field.

Electrical power is supplied to the Pravdinskoye field and the settlement of Poykovskiy from the "Pravdinskaya" 110/25/6 KV substation with two transformers of 16 MVA each. The electrical power is distributed via 35 KV lines to eight 35/6 KV transformer substations with an overall installed transformer capacity of 58 MVA. The "Pravdinskaya II" 110/35/6 KV substation with transformers of 40 MVA each was placed in service in 1975 in the region of the product depot.

The Ust'-Balyk oil field and the city of the Nesteyugansk received power from the "Ust'-Balyk" 220/35/10 KV substation with three transformers of 40 MVA each. To control the reactive power flows and the voltage levels, a 50 MVA synchrnonous compensator was installed at this substation. The electrical power is distributed via 35 KV power transmission lines to ten 35/6 KV substations with an overall installed transformer capacity of 85 MVA.

The "Yuganskaya" 110/35/6 KV substation with 2x40 MVA transformers was built to provide electrical power to the wells for the B10 oil horizon of the Ust'-Balyk oil field. Electrical power is provided to the Solkinskaya site from the "Solkinskaya" 110/35/6 KV substation with transformers of 16 MVA each. The electrical power is distributed via 35 KV power transmission lines to two 35/6 KV substations with an overall installed transformer capacity of 25.2 MVA.

The Western Surgut field receives electrical power from the "Zarya" 110/35/6 KV substation with two transformers of 16 MVA each and from the "Tovarnyy Park" ["product depot"] 110/6 KV substation with two transformers of 10 MVA each. The electrical power is distributed via 35 KV power transmission lines to three 35/6 KV substations with an overall installed transformer capacity of 33.2 MVA.

TABLE 1

Oil Fields	Loads of the Oil Pumping Stations of the Fields (in MW), for the Years						
	1974	1975	1976	1977	1978	1979	1980
Mamontovskoye	15.6	27.2	55.2	61.2	67.2	72.0	72.0
Pravdinskoye	26.3	35.1	40.2	43.2	44.2	44.5	45.0
Ust'-Balyk	42.0	50.1	56.1	51.0	44.0	37.0	39.0
Solkinskaya site	14.6	15.5	23.5	35.0	35.0	35.0	35.0
Western Surgut	21.9	22.6	25.0	30.6	30.6	30.6	30.6
The city of Surgut	21.0	30.0	31.2	36.0	41.2	46.4	52.0
Fedorovskoye	14.0	18.0	24.0	33.0	42.0	46.0	50.0

The "NPS" 110/6 KV substation with two transformers of 16 MVA each was brought on line to provide electrical power to the "Surgut II" oil pumping station.

Electrical power is supplied to the city of Surgut from the 220/110/10 KV "Surgut" substation at a voltage of 10 KV, from the "Pionerskaya" and "Stroitel'naya" 110/6 KV substations at a voltage of 6 KV and from the "Chernyy Mys" 110/10 KV substation at a voltage of 10 KV.

The Fedorovskoye field receives electrical power from the 110/35/6 KV "Fedorovskaya" substation with two transformers of 40 MVA each. In 1975, a 110 KV power transmission line to group pumping station No. 1 was placed in service, which was used temporarily for operation at a voltage of 35 KV.

In September of 1970, the two-circuit Surgut--Megion power transmission line was placed in service, which prior to 1973 had operated at a voltage of 110 KV. In 1973, one circuit was changed over to a voltage of 220 KV, and at the beginning of 1974, the second circuit was changed. The length of the power transmission line is 191 km; the carrying capacity at 110 KV is 120 MW and at 220 KV is 360 MW.

In the initial stage of the work, substations at the following voltages were connected to the 110 KV line:

--110/35/6 KV - "Ur'yevskaya" with two transformers of 10 MVA each, from which the "Ur'yevskaya" oil pumping station was powered;

--110/35/6 KV - "Vatinskaya" with 2x10 MVA transformers, from which the Vatinskoye field received power;

--110/35/6 KV - "Tayezhnaya" with 2x10 MVA transformers, from which the Megion field and the settlement of Megion receive power;

--The 110/6 KV "Megion" substation with two 110/6 KV transformers of 10 MVA each.

The "Megionskaya" 220/110/10 KV substation with autotransformers having a capacity of 4x125 MVA was constructed and placed in service in 1973 to shift the Surgut--Megion power transmission line over to a voltage of 220 KV. Because of the growth in the loads on the 6 KV side, the two 110/6 KV transformers of 10 MVA each were replaced with two 110/6 KV transformers of 40 MVA each, and somewhat later, two transformers of 40 MVA each at a voltage of 110/10 MV were installed at the substation to power the Nizhnevartovskaya oil pumping station.

After the Surgut--Megion power transmission line was changed over to 220 KV, the "Ur'yevskaya" oil pumping station was connected to the new 220/110/6 KV substation with 2x63 MVA transformers.

The "Vatinskaya" and "Tayezhnaya" substations were connected to the 110 KV power transmission line from the "Megion" substation.

The 110 KV power transmission line for the Aganskoye oil field was connected via a transit line to the Tayezhnaya" substation.

The dynamics of the growth in the electrical loads of the fields powered from the Surgut--Megion 220 KV power transmission line are shown in Table 2.

The Vatinskoye field at the present time receives electrical power from the "Vatinskaya" 110/35/6 KV substation with two transformers of 16 MVA each. The electrical power is distributed via 35 KV power transmission lines to two 35/6 KV substations with an overall installed transformer capacity of 25.2 MVA. The Aganskoye oil field receives power from the Aganskaya" 110/35/6 KV substation with two transformers of 25 MVA each. A 5.6 MW gas turbine electric power station is used as an emergency power source at the field. The Megion field receives power from the "Nizhnevartovskaya" 110/35/6 KV substation with 2x25 MV transformers and the "Tayezhnaya" substation with transformers of 2x10 MVA each. The consumers of the Megion Central Product Depot and the Nizhnevartovskaya head oil pumping station for the Nizhnevartovsk--Ust'-Balyk oil pipeline are powered from the "Megion" substation at a voltage of 6 KV.

Electrical power is supplied to gas refinery No. 1 at a voltage of 110 KV from the "Megionskaya" substation. Two transformers of 63 MVA each are installed at the refinery substation. Gas refinery No. 2 is powered from the 220 KV Surgut--Megion power transmission line. Two autotransformers of 125 MVA each are installed at the Substation.

Four central distribution substations at the following voltages have been built in the 110 KV electric power supply network for the Samotlor field [1]:

--110/35/6 KV - "Samotlor I" with 2x25 MVA transformers, powered from the 220/110/10 KV "Megion" substation via one dual circuit power transmission line;

TABLE 2

Fields	Load of the Oil Pumping Stations of the Fields (in MW), for the Years:						
	1974	1975	1976	1977	1978	1979	1980
Vatinskoye	17.5	17.5	18.0	18.5	20.0	20.5	21.0
Aganskoye	10.7	18.5	27.0	36.0	39.0	42.0	42.5
Megionskoye	18.0	18.0	20.0	23.0	23.5	25.0	26.0
Samotlorskoye	200	280	360	410	451	476	493

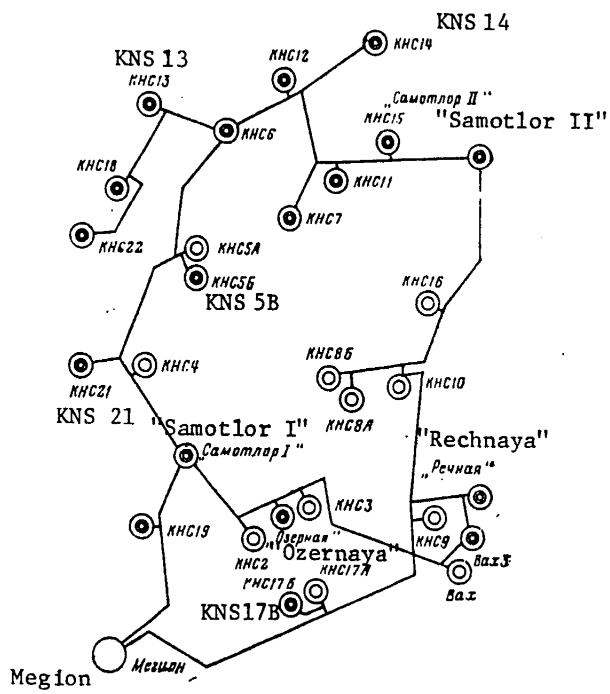

Figure 2. The layout of 110 KV substations at the Samotlor field.

Key: KNS = group pumping station.

--110/35/6 KV - "KNS 6" with 2x16 MVA transformers, powered from the "Samotlor I" substation;

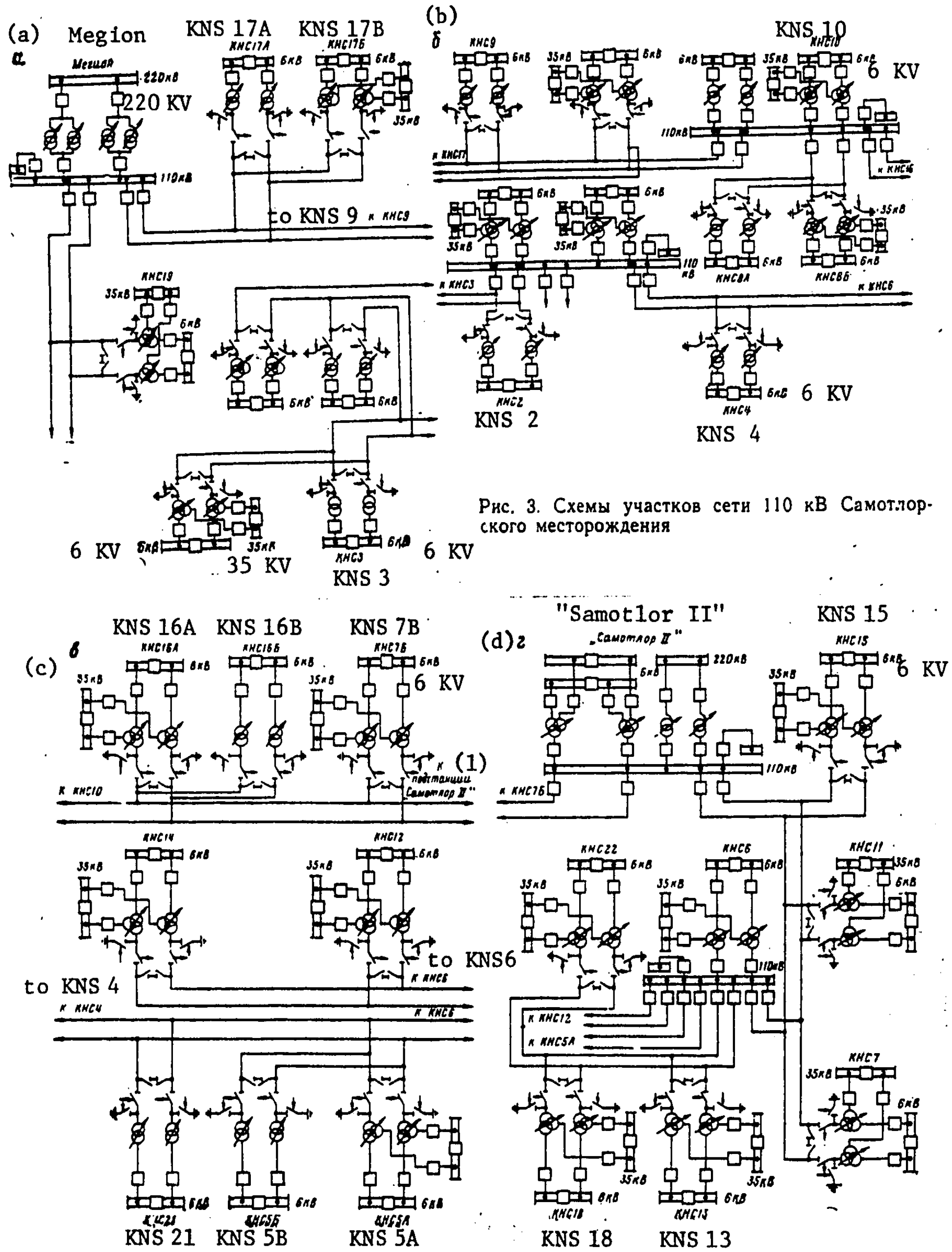

Рис. 3. Схемы участков сети 110 кВ Самотлорского месторождения

Figure 3. Circuits of the 110 KV network sections at the Samotlor field.

Key: KNS = group pumping station;

1. To the "Samotlor II" substation.

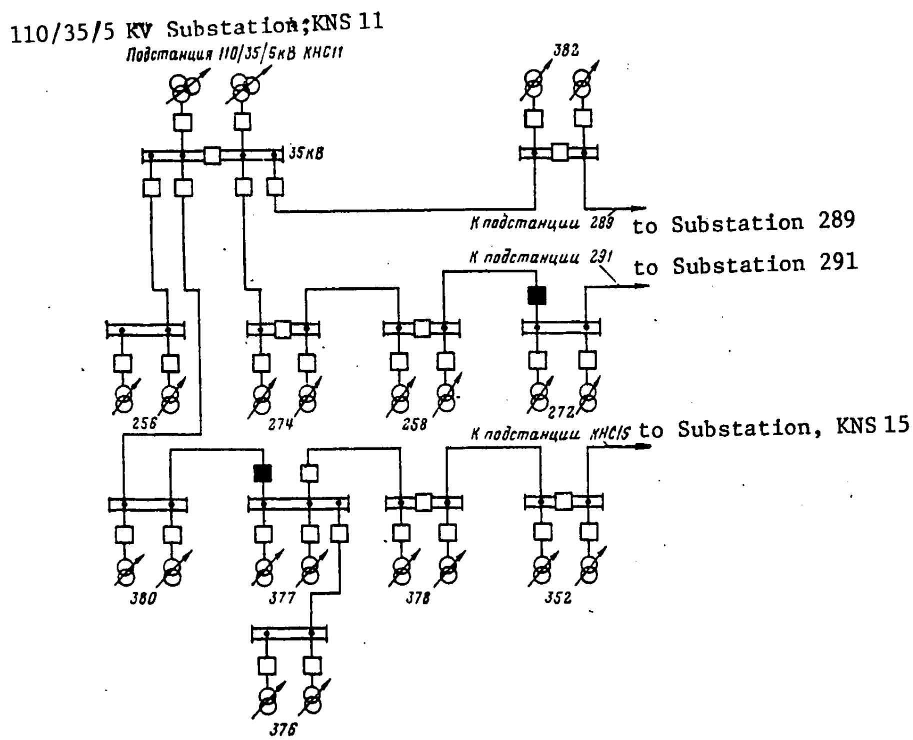

Figure 4. Scematic of the 35 K network sections of the Samotlor field, powered from KNS 11 [group pumping station 11].

--110/6 KV - "Samotlor II" with 2x40 MVA transformers, powered from the "Megion" substation via one dual circuit power transmission line; in 1978, the 500 KV "Samotlor II" was also built at the "Samotlor II" substation with the supply from the 500 KV Surgutskaya GRES--"Samotlor II" power transmission line;

--110/6 KV - the "KNS 10" with 2x16 MVA transformers, powered from the "Megion" substation.

--The loads of the group and output pumping stations, the fully equipped collection points, the Belozernyy product depot and the water intakes are powered from 18 main step-down 110/35/6 KV substations and 14 substations at 110/6 KV. They are all deep entrance substations. The layout of the 110 KV substations of the Samotlor field is shown in Figure 2 while the circuit schematics for the 110 KV network sections of this field are shown in Figure 3.

Electrical power is distributed among the groups of oil wells at a voltage of 35 KV with a deep 35 KV entrance directly to the wells. The 35 KV power grids are made in a ring configuration with 100 percent back-up from adjacent substations. In the normal mode, the 35 KV network is open at one of the substations.

110/35/6 KV Substation, KNS 15

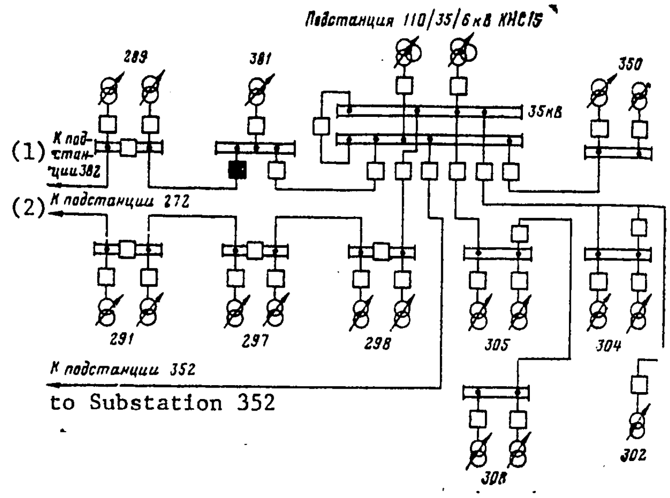

Figure 5. Circuit schematic of the 35 KV network sections of the Samotlor oil field powered from KNS 15 [group pumping station 15].

Key: 1. To substation 382;
2. To substation 272.

The cross-sections of the 35 KV power transmission lines connecting the two 110/35/6 KV substations were taken as the maximum permissible values for the adopted type of supports: 150 mm^2, something which provides for transmitting a power sufficient not just to supply the groups of wells, but also part of the load of an adjacent 35 KV substation in case one transformer fails in it or it is completely disconnected.

The cross-sections of the wires on the radial portions of the network were selected based on an economical current density. The supports for the 35 KV network were made of metal with a single circuit strung on them. In the ring networks, where all of the substations are through-working substations, single circuit lines, in the case of bilateral feed of consumers, provide for the requisite degree of power supply reliability.

The 35 KV line routes are run along roads or the routes of pipelines where possible, so as to provide for access to the power transmission line in case inspection or repair is necessary.

In all, it is planned that 257 substations at 35 KV and 455 km of 35 KV networks will be constructed in the Samotlor oil field.

A characteristic schematic of the 35 KV network for the Samotlor oil field, which is powered from the 110 KV substation in the case of KNS 11 and KNS 15 [group pumping stations 11 and 15], is shown in Figure 5. The three place figures on the schematic designate the numbers of the well groups.

Electrical power is supplied to the city of Nizhnevartovsk from the 110/35/6 KV "Nizhnevartovskaya I" substation with 2x25 + 1x40 MVA transformers and the "Obskaya" substation with 110/10 KV transformers with a capacity of 2x25 MVA, as well as from four 35/6 KV substations. The municipal 110 KV substations are powered from the "Megion" substation via a two-circuit 110 KV power transmission line.

To regulate the reactive power flows and voltage levels, two compensators of 15 MVAR each have been installed at the 110 KV "Nizhnevartovskaya I" substation.

The Electrical Loads of the Sovetskiy Oil Field

Years	1974	1975	1976	1977	1978	1979	1980
Electrical loads, MW	23.0	30.0	35.1	39.1	45.1	46.1	48.0

The Sovetskiy field receives electrical power from 110/35/6 KV "Sovetskaya" substation with 2x63 MVA transformers, powered from the "Megion" substation via a two-circuit 110 KV power transmission line, which was built with the dimensions of a 220 KV power transmission line. Electrical power is distributed via 35 KV lines to nine transformer substations with an overall installed transformer capacity of 53 MVA. The consumers of the "Aleksandrovskoye" head oil pumping station of the Aleksandrovskoye--Andzhero-Suzhensk oil pipeline are powered from the "Sovetskaya" substation at a voltage 6 KV. The Strezhevoy settlement receives power from the "Strezhevoy" 110/35/10 KV substation with 2x25 MVA transformers, powered from the "Sovetskaya" substation via a two-circuit 110 KV power transmission line.

The intense growth in the volume of gas extraction and transport in the northern regions of the Tyumenskaya oblast is responsible for a significant growth in loads and electric power consumption.

The levels of electric loads and electric power consumption for gas extraction and transport are shown in Table 3.

The major consumers of electric power in gas fields are the complete gas preparation installations, the design load of which amounts to 1.8 MW. The major electric power consumers in gas transport are the compressor stations. The design load of one compressor station operating on the Nadym--Punga gas trunk pipeline amounts to 3 MW. The comprehensive gas preparation installations and the compressor stations for trunk gas pipelines belong to first category consumers in terms of the degree of electric power supply reliability.

TABLE 3

Electrical Loads and Electric Power Consumption	Years					
	1975	1976	1977	1978	1979	1980
Gas extraction:						
Load, MW	24	45	78	114	152	185
Electric power consumption, 10^6 KWH	96	180	300	460	600	800
Gas transport:						
Load, MW	24	35	44	166	420	680
Electric power consumption, 10^6 KWH	96	140	180	680	1,800	2,800
Total:						
Load, MW	48	80	122	280	572	865
Electric power consumption, 10^6 KWH	192	220	480	1,140	2,400	3,600

At the present time, there is no state power system network in the northern regions of the Tyumenskaya oblast where the gas fields are located and the gas pipelines run. Electrical power is supplied to cosumers from independent electrical power sources.

Gas turbine PAES-2500-T/6.3 electric power stations with a capacity of 2.5 MW, PAES-1600-T/6.3 with a capacity of 1.6 MW and 6GChN-36/45 diesel electric power plants with a capacity of 0.63 MW and MG-3500 motor generator sets with a capacity of 3.5 MW are used as the electric power sources.

The transportable auotmated gas turbine PAES type electric power stationa operate either independently or in parallel. Included in the complement of the electric power stations are a 6 KV distribution switchgear unit and an outdoor transformer substation with 6/35 KV transformers. The voltage is fed via a 35 KV power transmission line to the installations where 35/6 KV transformers are installed. The 6 KV power transmission lines are run to facilities located close to the electric power stations. A drawback to the power stations cited here is the small unit capacities, something which with a growth in the electrical loads leads to the necessity of installing a large number of such plants and requires the construction of large rooms.

At the present time, five units of gas turbine PAES-2500 and PAES-1600-T/6.3 electric power stations have been installed to provide electric power to the comprehensive gas separation facilities of the Medvezh'ye field.

Electric power is supplied to the "Longyuganskaya" and "Sorumskaya" compressor stations of the Nadym--Punga gas pipeline from a deisel electric power station with fourteen 6GChN-36/45 generator sets; the "Kazymskaya" compressor station receives power from a deisel plant with twenty 6GChN-36/45 generator sets.

The construction of electric power stations in the city of Nadym, as well as the settlements of Pangody, Kazym and Yagel'nyy having a capacity of 48 to 60 MW with units of 12 MW each based on gas turbine engines is planned to power the growing electrical loads of the gas fields and trunk gas pipelines during 1976--1980. It is necessary to construct about 3,000 km of 110 KV power transmission lines to support gas extraction.

CHAPTER TWO. ELECTRIC EQUIPMENT FOR DRILLING RIGS

General Information

The conduct of drilling operations in Western Siberia is characterized by a number of distinctive features, since in northern regions they differ sharply from those of the central Ob' in that the depths of the wells are increased; the geological conditions for well drilling are complicated, which are due to the presence of permafrost and gas strata in the cross-sections of the deposits, which necessitate the use of multiple drill string wells. The indicated regions are isolated from the main river route of the Ob' river. The severe climatic conditions sharply reduce the pace of drilling operations in the winter.

Because of the boggy nature of the territories of the oil fields being developed, a group method of multiple drilling has become widespread. In this method, an artificial platform with a rail overbridge is constructed, while the drilling rig, which is mounted on a base with railroad bogies, moves from well to well (within the bounds of the "cluster") by means of its own drive or tractor. In the group method, the majority of the wells is drilled by means of controlled directional drilling. The number of wells in the "cluster" fluctuates from 3 to 22.

One of the major technical solutions which was realized in the area of drilling was the electrification of drilling operations in Western Siberia [5]. This made it possible to standardize the drilling rigs and improve their set-up capability, sharply curtail the amount of time the boreholes are idle, reduce their fire hazard, as well as reduce the watch crews of the drilling brigades and increase the production efficiency. All of these factors exerted a significant influence on improving the technical and economic indicators for drilling.

An analysis of domestic and foreign experience with the operation of drilling rigs intended for drilling deep oil and gas wells attests to the substantial advantages of electrical drive for drilling rigs as compared to other kinds of power drives. The guaranteed service lives of electric motors for the main drives of drilling rigs is substantially greater than the engine service lives of diesel engines. As a result, the downtimes for electrified drilling rigs are curtailed by 75 percent as compared to diesel installations.

It has been calculated that the annual operational expenditures where electric drives are used are 3.75 times less than in the case of diesel drive use.

The application of electric drives makes it possible to change over from a group power drive for the main mechanisms of the drilling rig (both for drilling rigs with diesel and diesel-hydraulic drives) to a single drive. In this case, one dispenses with the necessity of strict alignment of the mutual position of the majority of drilling equipment and power units, since the complex mechanical couplings between them are eliminated.

Because of the complexity of mastering the oil and gas bearing province of Western Siberia, improving the set-up capability of drilling rigs for this region takes on exceptionally great significance. The electrification of drilling rigs in the Main Tyumen' Oil and Gas Administration has promoted a significant reduction in the timeframes for their construction.

As a result of the fact that electric motors have a high efficiency, and because they are directly coupled to the actuating mechanisms, the overall efficiency of electric drives for drilling rigs considerably exceeds the efficiencies of other kinds of drives.

Type of Drill Drive	Efficiency, %
Electric, alternating current	70 - 73
Diesel-electric, direct current	60 - 70
Turbo-electric, alternating current	49 - 51
Diesel	60 - 62
Diesel-hydraulic	52 - 54

Besides the advantages enumerated above, the application of electric drive for drilling rigs makes it possible to realize a wide selection of primary motors (asynchronous with a short-circuited or phase rotor, symchronous, direct current), improves the layout of the drilling equipment, simplifies the control of the drives, promotes the automation of the production processes, eliminates the fuel oil system, decreases the metal input requirement for the drilling rig and reduces the expenditures both for its construction and for drilling the wells by a factor of 1.5 to 2.

The advantages of electric drives for drilling rigs, in conjunction with the advantages of socialist management of the national economy, which is brilliantly manifest in the comprehensive electrification of the entire nation, have assurred the universal and widescale introduction of drilling rigs with electric drives.

In May of 1967, a well was drilled with an electric drive at the Ust'-Balyk field in Western Siberia. High technical and economic indicators were achieved in drilling this well.

The transition to electrified drilling rigs in the Main Tyumen' Oil and Gas Administration was accomplished by changing the existing fleet of drilling rigs with diesel-hydraulic drives (BU-75BrD, BU-80BrD and "Uralmash-5D") over to electric drive and supplementing the fleet of drilling rigs with installations having BU-75BrE and BU-80BrE-1 electric drives.

As a result of analyzing the operational experience with drilling rings having electric drives, the Main Tyumen' Oil and Gas Administration developed the engineering documentation for the changeover of the BU-75BrD, BU-80BrD and

"Uralmash-5D" drilling rigs to electrical drive. The following design solutions were taken as the basis for the modernization of the drilling rigs:

--The drives for the drill pumps and the drilling hoist were made the same (synchronous SDZB-13-42-8A motors rated at 450 KW, 6,000 V, 750 r.p.m.);

--A MEP-800 electromagnetic powder clutch was used as the starting unit for the drilling hoise drive;

--YaKNO-6 cells were adopted for the 6 KV switchgear.

Later, the hydrodynamic BU-75 and BU-80 of the drilling rigs started to be replaced by TEP-4500 electromagnetic powder brakes.

Such an approach to the choice of the electric drive for the drilling rigs made it possible to standardize and significantly simplify the electrical circuits for the drilling rigs, increase the set-up capability and the safety of servicing them; it also made it possible to dispense with the intermediate voltage of 500 volts and eliminate the TMB type power transformers and the SB-58 magnetic motor control stations; as well as create conditions for maintaining practically any requisite value of the power factor.

Since 1971, BU-75BrE drilling rigs have been arriving at the Main Tyumen' Oil and Gas Administration; asynchronous AKB-12-39-6 motors at 320 KW and 6 KV have been installed in these rigs as the drive for the hoist. KRNB-6M distribution switchgear (RU) is used to distribute the electrical power.

The same 6 KV distribution switchgear is supplied as part of the equipment package for the BU-80BrE-1 drilling rigs, which began to arrive at the Main Tyumen' Oil and Gas Administration at the end of 1973. Synchronous SDZB-13-42-8A motors at 450 KW and 6 KV as well as electromagnetic induction EMS-750 slip clutches were used in the hoist drive for these rigs. Electromagnetic powder TEP-4500 brakes were used as the auxiliary brake for the hoist.

The comprehensive approach to the electrification of drilling operations has made it possible to accomplish the technical re-equipping of the fleet of drilling rigs in Western Siberia in an extremely short period of time.

An analysis of statistical data from the Main Tyumen' Oil and Gas Administration shows that for drilling using rigs with electric drives, the schedule speed is 11.5 percent higher, the penetration per bit is 15 percent higher, while the production cost per meter of penetration is 13 percent lower than for drilling with diesel driven rigs. This attests to the high effectiveness of drilling operation electrification in Western Siberia.

The Drilling Hoist

The start of the electrification of drilling operations in Western Siberia coincided with the performance of trial industrial tests of the induction EMS-750 and magnetic powder MEP-800 clutches, designed for the electrical drives of drilling rigs, in various oil regions of the nation. In Western Siberia, when drilling rigs with diesel drives were retrofitted with an electric drive, powder clutches were employed and a broad set of studies was made of the electric drive for the drilling wench using these clutches.

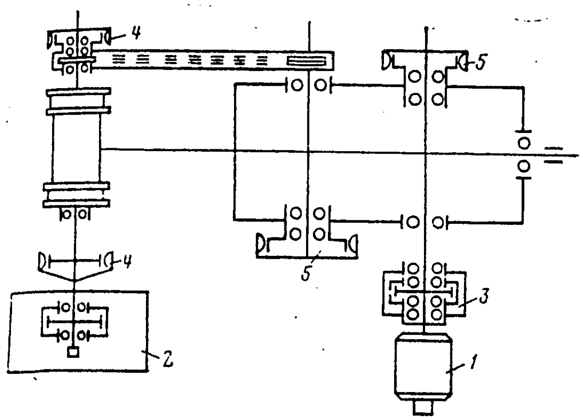

Figure 6. Kinematic schematic of the drill hoist for the Bu-80 drilling rig.

Key: 1. SDZB-13-42-8A motor;
2. TEP-4500 brake;
3. MEP-800 clutch;
4. ShPM-1070 clutch;
5. ShPM-700 clutch.

A kinematic schematic of a drilling hoist with an MEP-800 clutch for a BU-80E rig, retrofitted with a DVS [unknown type of synchronous electric motor]. The wench has three hoist speeds of 0.428, 0.91 and 1.725 m/sec, corresponding to gears I, II and III. Such a kinematic variant, which is distinguished by the direct coupling of the input shaft of the transmission to the driven shaft of the magnetic particle clutch, was adopted by working from the necessity of simplifying the kinematic configuration of the hoist and the convenience of the equipment layout in units. The moment of inertia of the speed change gearbox of the BU-80E drilling rig (retrofitted with a DVS) is almost twice the moment of inertia of the speed change gearbox of the BU-80BrE-1 rig, something which had an unfavorable impact on the thermal mode of the magnetic particle clutch.

We shall analyze the operational modes of the particle clutch: operational, nonoperational (the moment limiting mode) and semi-operational.

The operating mode of the clutch is characterized by the fact that with a constantly rotating drive motor, during the pauses between hoistings, the MEP-800 electromagnetic powder clutch and the ShPM-1070 air flex clutch are disconnected on the shaft of the hoist drum. When hoisting the next string of the boring tool, the drill operator engages the air flex clutch beforehand and thereby couples the hoist drum through the transmission to the driven part of the electromagnetic clutch. The acceleration of the hoist drum begins after current is fed to the excitation winding of the MEP-800. Upon completing the lift, the ShPM-1070 clutch is first disengaged, and thereafter the MEP-800 clutch, something which makes it possible to reduce the flywheel masses participating in the run-down.

In this operational mode of the electric drive, the acceleration of the hoisting system occurs smoothly, while the choice of the gaps takes place without shocks. The energy losses during run-up of all of the drive masses occur in the MEP-800 starting clutch.

The moment limiting mode is characterized by the fact that a nominal excitation current constantly flows in the excitation winding of the powder clutch. Its driving and driven parts are coupled together and constantly transmit the rotational motion of the entire transmission as far as the driving portion of the operating ShPM-1070 air flex clutch. The hoist drum is connected to the rotating electrical drive in this mode by means of filling the ShPM-1070 clutch with compressed air.

During the run-up of the hoist drum, the ShPM-1070 clutch slips. If the moment of the ShPM-1070 clutch exceeds the moment of the MEP-800 clutch before the completion of the run-up, then as a result of the application of the dynamic moment to the latter, a short term reduction in the angular speed of its driven shaft is possible with asimultaneous decrease in the slipping of the air flex clutch. Following the complete engaging of the ShPM-1070 clutch, the further run-up takes place only with the action of the moment transmitted by the MEP-800 clutch.

In this mode, the bulk of the energy losses occur in the ShPM-1070 starting clutch, something which causes it to wear rapidly. The overall run-up energy losses though, disipated in both clutches, are less than in the operational mode, since a significant part of the drive masses is rotated beforehand.

The semi-operational mode of the electromagnetic powder clutch is a variant of moment limiting operation and is distinguished by the fact that in the period between hoistings, a small preliminary excitation current flows in the excitation winding for the powder clutch. At this excitation current level, the moment transmitted by the MEP-800 clutch is insignificant and is sufficient only to rotate the unloaded transmission running up to the ShPM-1070 clutch. The hoist drum is coupled to the rotating transmission just as in the case of moment limiting operation, i.e., by means of the ShPM-1070 clutch.

In the process of turning on the hoist drum, the driven part of the powder clutch is loaded with static and dynamic moments, because of which, the angular speeds of this portion of the powder clutch, and correspondingly, the transmission fall off rapidly and both parts of the ShPM-1070 clutch engage at a relatively low rotational speed of the drum. During the period of reducing rotational speed of the transmission, the utilization of the stored kinetic energy of the rotating masses which decreases with time provides for a soft change in the gaps in all links of the hoist system transmission. By the point in time of complete engagement of the air flex clutch, provisions are made automatically with a time delay for the forced excitation of the MEP-800 clutch; the subsequent run-up of the hoist system takes place with the action of the moment transmitted by the MEP-800 clutch. The overall energy losses during run-up in this mode are distributed among the ShPM-1070 and MEP-800 clutches. The distribution of the losses can be accomplished in accordance with the heat disipating capabilities of the clutches by means of selecting the level of the preliminary excitation current for the MEP clutch, the time delay between turning the ShPM clutch on and the delivery of the forcing current to the MEP clutch as well as by varying the rate of filling the ShPM with compressed air. The distribution of the losses depends primarily on the ratio of the moments of inertia of the rotating parts of the hoist system and those which are being accelerated.

The control circuitry for the clutch is shown in Figure 7.

220 VAC

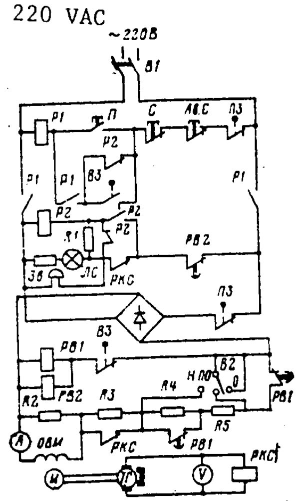

Figure 7. Control circuit for the MEP-800 magnetic particle clutch.

Key: B7-B3. Switches;
P-1, P2. Electromagnetic relays;
R1-R5. Resistors;
PB1-PB2. Time delay relays;
PKC. Speed monitor relays;
П, C, Aв.C. Control pushbuttons;
П3. Travel switch;
ТГ. Tachogenerator;
M and OBM. Clutch and excitation winding;
A, U. Monitor and metering instruments;
ЛC. Signal lamp;
Зв. Bell.

In the operational mode, switch B2 is in position 0 and the level of the clutch excitation current is zero. When the ShPM-1070 clutch is engaged, the limit switch B3, which is mechanically coupled to the control valve for the ShPM, opens the coil circuit of relay RB1, which feeds the instruction for forced excitation of MEP clutch after a time delay of 1 to 1.5 seconds. When the rotational speed of the driven shaft of the MEP reaches 95 percent of the nominal, the voltage of the tachogenerator ТГ, mounted on the shaft of the MEP-800 clutch, becomes sufficient to actuate the PKC relay. Resistor R_3 is inserted in the clutch excitation winding circuit, the OBM, where this resistor reduces the current. The removal of forced excitation, related to the completion of the run-up, retards the process of overregulation of the hoist drive acceleration. Upon completing the lift, the disconnection of ShPM-1070 clutch removes the excitation from the MEP.

In the semi-operational mode, a preliminary excitation current equal to 10 to 15 percent of the nominal when the ShPM-1070 clutch is disconnected is established in the MEP excitation winding by means of switch B2, which is in position ПВ. When the ShPM-1070 is turned, relay RB1 feeds the forcing or working current to the MEP clutch with the requisite time delay for filling the clutch. When small loads are applied to the driven shaft of the clutch, its rotational speed falls off insignificantly, the PKC [speed monitor relay] is not cut off and the forced excitation current is not fed out.

The protection circuitry operates in the following manner. When the ShPM clutch is turned on, cutout switch B3 de-energizes relay RB2 with a time delay of 10 to 12 seconds, equal to the permissible drive acceleration time. If the run-up time of the drive has exceeded this delay, i.e., the MEP clutch is overloaded, then the contact of RB2 will close sooner than the contact of PKC opens, and relay P2 is actuated. The signalling actuates (bell Зв and light ЛС), which remains turned on until the end of hoisting the string. When the ShPM-1070 clutch is cut-off, switch B3 cuts off the circuit of relay P1 which feeds voltage to the control circuit for the MEP clutch. After the elimination of the cause of the overload, the circuit is reset by pushbutton П and operation in a non-operating mode is possible when switch B2 is set in position H. Satisfactory distribution of the thermal load between the MEP-800 and ShPM-1070 clutches is possible only when the MEP clutch functions in the semi-operational mode. For this reason, this mode is recommended as the major one. Studies have been shown that it is essential for the operation of the MEP clutch in the operating mode that it have a heat dissipating capability of 25 KW and a maximum moment of 13 KN·m.

For the retrofitted BU-75E drilling rig, the energy losses dissipated in the particle clutch in the operation mode do not exceed the heat dissipating capacity of the MEP clutch. Therefore, in the hoist drive for this rig, the MEP clutch can be used in operational and semi-operational modes. The nonoperational mode is not reasonable for this rig, since all of the losses during the run-up time of the drive are dissipated primarily in the ShPM-1-70 clutch.

As was noted earlier, series produced BU-80BrE-1 drilling rigs started to arrive at Glavtyumenneftegaz in 1973, where induction EMS-750 slip clutches were used in the hoist drives. Studies performed on the U80BrE-1 rig showed that the maximum moment of the EMS-750 clutch is 18,380 N.m at an excitation current of 51 amps, a figure which is considerably greater than the maximum moments of the MEP-800 clutch and the drive motor with a capacity of 450 KW. Because of this, with the existing excitation system for the motor, there are cases where it "stalls" (gets out of sync). Studies have demonstrated the expediency of using thyristor excitation for the synchronous motor, increasing its overload capacity and developing a more sophisticated control station for the clutch.

Braking the Drill Hoist

The development of well drilling engineering and technology makes the additional demands of further refining the braking devices in the drives of modern drill hoists. Hydrodynamic brakes with a closed water cooled system have found wide-scale applications as such brakes. The drawbacks to these brakes are: unsatisfactory control properties, the impossibility of obtaining large braking moments at low bit descent speeds, etc. A number of the technical problems which come up when automating the production process operations in the case of hoisting and lowering operations (for example, the precise stopping of the hook block during hoisting, the seating of the bit on the pneumatic wedges, etc.), cannot be solved by using a hydrodynamic brake. For this reason, the EMT-4500 electromagnetic induction brake and the TEP-4500 particle break were designed and put in production by industry.

The technical characteristics of the EMT-4500 and TEP-4500 electromagnetic brakes are given in Table 4.

A characteristic feature of the magnetic particle brake is the fact that the braking moment produced by it is practically independent of the rotational speed. The magnitude of the braking moment is governed by the excitation current, something which makes it possible to obtain stringent mechanical characteristics.

A consequence of the change in the braking moment of the TEP-4500 brake in a range from zero to the maximum was the possibility of continuous smooth control of the drill bit descent speed, regardless of the weight, as well as the possibility of stopping it and holding it in suspension, obtaining slow bit lowering speeds, and when approaching the rotor platform, smoothly seating it on the rotor or the pneumatic wedges without using a band-and-block brake. This makes it possible to sharply curtail the wear and consumption of brake blocks, bands and hoist drum pulleys.

The studies which have been made have demonstrated the possibility of operating the TEP-4500 brake with a negative ambient air temperature without forced air cooling. The time constants for brake heating also promote this: 130 minutes for the excitation winding and 80 minutes for the rotor.

The study of brake operation during bit feed to the bottom when drilling a well is of special interest. As operational experience has shown in Western Siberia with RPDE-3 bit feed controllers, their application is possible only from a depth of 1,600 m. When using the TEP-4500 brake, one can provide for practically any feed speed and in this case, maintain a specified load on the bit with an accuracy of $\pm$ 2 tons.

A recording of the bit feed to the bottom using a TEP-4500 brake is shown in Figure 8.

The most efficient control of the drilling hoist is possible only in the case of combined control of the particle and band brakes. In this case, the rate of descent of the string from the maximum to the minimum value should be reduced by the particle brake, as it posses the greatest heat dissipating capability and good control characteristics; it should also limit the maximum descent speed. The preliminary reduction of the descent speed of the string by the magnetic particle brake down to the minimum value of 0.2 to 0.5 m/sec makes it possible to easily accomplish the precise stopping of the string by the band brake. In this case, the wear on the blocks of the band brake will be sharply reduced.

Such a control algorithm for the hoist during the lowering of the drill bit, in which the particle brake is not used to completely brake the hoist, made it possible to eliminate the question of the necessity of its demagnetization and significantly simply the circuitry of the control station for the particle brake (Figure 9).

TABLE 4

Type of Brake	M_H, KN·m	M_{max}, KN·m	n_H r.p.m.	$P_{exc.}$ KW	J_{rot}, kg·m^2	K_B, kg/KN·m	Overall Dimensions, mm	Weight, kg
EMT-4500	45	56.7	500	14	1,040	107.5	1,819x 1,700x 1,495	6,100
TEP-4500	45	55	550	2	3.75	72.8	1,290x 1,500x 141P [sic]	4,000

The Technical Characteristics of the Control Station for the TEP-4500 Brake

The voltage of the alternating current mains, volts	200 + 15, -30
Frequency, Hz	50
Range of change in the current level (in one winding), amperes	0--5
Overall dimensions, mm	300 x 250 x 250

The brake windings, which are connected in parallel, are connected to the controlled thyristor rectifier D3 with the neutral diode D1. The rectifier is pwered from the two phases of a 220 volt AC main, something which makes it possible to significantly reduce the time for the current to rise in the brake excitaton windings up to the specified level.

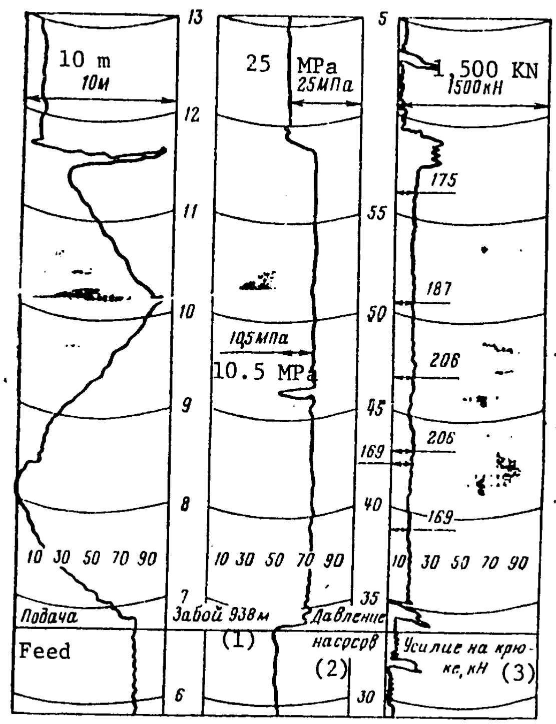

Figure 8. Recording of the feeding of a drill bit to the bottom using a TEP-4500 brake.

Key: 1. Bottom, 938 m;
2. Pressure of the pumps;
3. Force on the hook, KN.

When drilling a well, switch B3 is set in position П. Continuous control of the braking moment is accomplished by variable resistor R5, which changes the amplitude of the reference voltage fed to the control lead of thyristor D3. The latter is triggered if the current feedback voltage across resistor R1 is less than the reference voltage fed to its control electrode. In this case, numerical pulse control is possible, where the controlled voltage consists of periodically repeating trains of sinusoidal pulses. The ratio between the number of pulses in a train and the number of passed pulses governs the current level in the brake excitation windings.

In the descent mode, the rectifier is controlled by the feedback voltage based on the bit descent speed. The feedback level is governed by the resulting regulated voltage from zenir diodes D7-D13. One of three descent speeds is set by switch B3. The preliminary reduction of the descent speed of the bit, when the elevator approaches the rotor platform, is accomplished by throwing the handle of the command controller B2 over to position 1. When it is necessary to completely brake the hoist with the particle clutch (for example, in an emergency situation), the command controller is set in position 2.

When the hoist brake is released, the string is accelerated with the action of its own weight. When the descent speed increases up to the value determined by the position of switch B3, the speed feedback begins to operate, which causes an increase in the current level in the particle brake excitation winding. The current level is governed by the moment from the weight of the drill string.

Prior to stopping the string, the command controller B2 is set in position 1; in this case, the speed feedback gain causes the descent speed to fall off down to the minimum value (the creep speed). The string is finally braked and stopped by the application of the band brake. Because of the preliminary reduction of the speed down to the creep value, precise stopping of the string is assured.

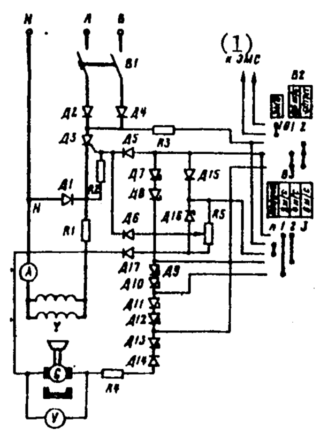

Figure 9. Schematic of the control station for the TEM-4500 brake.

Key: 1. To the EMS [not further defined].

Because of the good control properties of the electromagnetic particle brakes, it has truly become possible to remotely control the drill hoist. A prototype of a remote control system successfully underwent industrial tests in a BU-80BrE-1 drilling rig in the Samotlor field, and the system was recommended for series production. A mechanical (band type) brake and a particle brake are used in this system.

The superimposition of the band brake is accomplished not by the muscular effort of the drill runner, but by the persistent force of a precompressed spring. The releasting of the brake (the backing-off of the brake bands from the band wheels) is accomplished by feeding compressed air into a pneumatic cylinder. In cases where the permissible descent speed of the bit is exceeded, the actuation of the anti-drag-in device, in case the voltage or air is lost, or in case of wear of the blocks for the brake bands, compressed air is released from the cylinder and the emergency mechanical brake is applied.

The electromagnetic particle brake performs the role of an operational braking device during the hoisting and lowering operations and the role of a device for feeding the bit to the bottom of the well. The system provides for the capability of operational control of the mechanical brake by means of an electropneumatic pressure regulator. The regulator current is controlled by the command unit on the control console of the drill runner, on which the command unit for the particle brake is also installed. Remote control significantly facilitates the work of the drill runner, increases the safety in the performance of the hoisting and lowering operations and creates the prerequisites for the automation of the hoisting and lowering process. It has become possible to lower the hoisting block down to ground level, and set up the drill runner control panel at any point which is safe and operationally convenient.

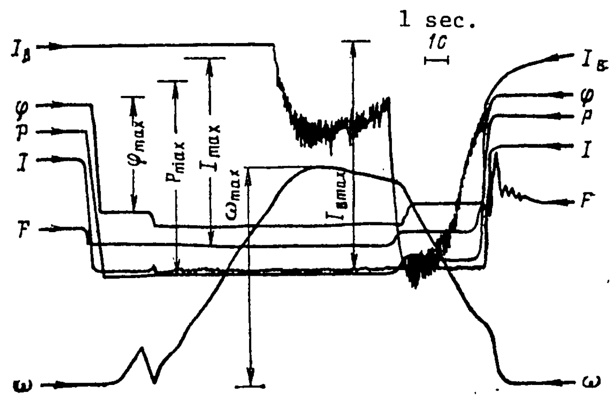

Figure 10. Oscilloscope trace of the boring tool descent for the case of combined control of band and magnetic particle brakes.

Key: I_B is the excitation current for the TEP-4500 brake ($I_{B\ max}$ = 11.3 amps);

I is the control current for the electropneumatic controller (I_{max} = 136 MA [sic]);

p is the air pressure in the pneumatic cylinder of the spring driven pneumatic drive of the band brake (p_{max} = 0.48 MPa/cm^2);

ϕ is the angle of rotation of the brake shaft of the band brake (ϕ_{max} = 0.29 rad);

F is the force on the push rod of the spring-pneumatic drive;

ω is the rotational speed of the drum shaft of the hoist (ω_{max} = 47.5 sec^{-1}).

An oscilloscope trace of the descent of the boring tool (78 strings) for the case of combined control of the band and particle brakes is shown in Figure 10. During the operation of the electromagnetic particle clutches and brakes, it is important to replace ferromagnetic powder which has worn out on a timely basis. The rate of its wear depends on the operational mode of the clutches and brakes, and for this reason, its service life can vary from three months up to two years. A consequence of the mechanical wear of the powder is also the change in its magnetic properties, and consequently, in the moment developed by the particle clutches and brakes. Particle wear is accompanied by its pulverization and oxidation, as a result of which, the iron oxide content in it increases and the free-flowing mass and magnetic permeability fall off.

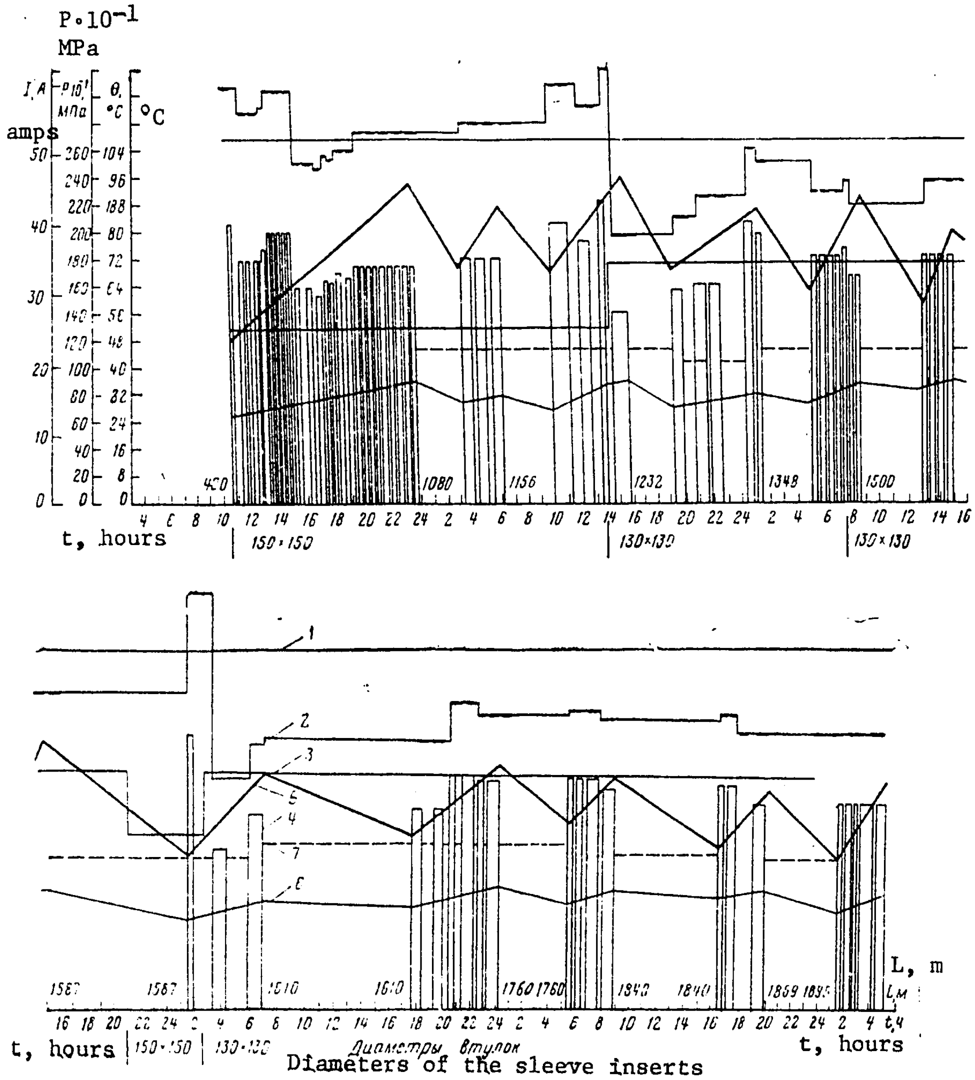

Figure 11. Graph of the loading of the U8-4 drill pump and the SDZB-13-42-8 electric drive motor during well drilling in the Samotlor field:

[Key to Figure 11, continued from previous page]:

1. The nominal motor current;
2. The motor current when operating under load;
3. The nominal travel of the pump for each insert sleeve diameter;
4. The pressure developed by the pump during drilling;
5. The motor heating temperature under load;
6. The ambient temperature during the driving of the wells;
7. The no-load motor current.

Production has been set up in the Main Tyumen' Oil and Gas Administration for particle wear indicators based on the change in the magnetic permeability of the powder, something which makes it possible to resolve the issue of the necessity of replacing the magnetic powder directly on the drilling rig. The operational principle of the instrument is based on the utilization of the Hall effect: the voltage picked off from a Hall transducer is directly proportional to the magnetic field induction in a direction perpendicular to the plane of the transducer. The scale of the instrument is graduated in powder wear percent as compared to a new powder, something which makes it possible to eliminate errors caused by a variation in the temperature and magnetic fields. A mark for the permissible powder wear is made on the scale graduation for clutches and brakes, which is determined by the criterion of the permissible reduction in the moment of the machines.

Drilling Pumps

In accordance with the stipulations of All-Union Standard 26-02-807-73, the BU-2500 and BU-3000 drilling rigs are equipped with drill pumps having a drive capacity of 600 to 750 KW. At the present time, the BU-80-BrE-1 rigs being delivered to Western Siberia are outfitted with BrN-1 pumps, driven by synchronous motors with a capacity of 450 KW. Two pumps each are installed on each drilling rig. They are connected to the motors by means of a doubled ShPM-500 air flex clutch.

A correlation analysis of the drilling modes has made it possible to establish the inter-relationship between the mechanical drilling rate the consumption of drilling mud. The relationships obtained attest to the expedience of increasing the hydraulic power of the drilling pumps. In this regard, the U8-4 and BrN-1 drilling pumps in the Main Tyumen' Oil and Gas Administration are being replaced with pumps of a greater hydraulic power (U8-6M), thereby assuring a transition to forced drilling modes using the hydraulic excavation effect of the destruction of the rock. The "Uralmash" plant supplies these pumps in complete packages with motors having a capacity of 630 KW.

Well drilling in Western Siberia is characterized by relatively small time expenditures for the drilling process, the use of turbine drilling and hydraulic excavator type bits, the widescale utilization of forced drilling as well as highly mechanical, high yield speeds and travel per bit. Thus, the time for drilling a 25 meter pole is commensurate with the time for adding on to the boring tool.

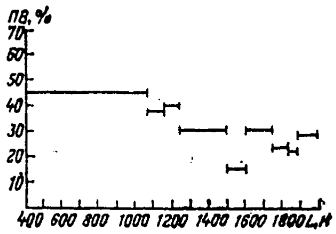

Figure 12. The amount of time the pump motor is turned on as a function of the well drilling interval [in meters].

Time Expenditures for Drilling and Building Up the Boring Tool

Drilling, Meters	Time for Drilling a 25 Meter Hole, Minutes	Time for Adding On to the Boring Tool, Minutes
0-500	8-12	8-20
500-1,000	10-17	9-11
1,000-1,500	20-25	9-11
1,500-2,000	20-30	10-12
2,000-2,500	25-40	13-15

Studies which have been carried out in the Samotlor field have made it possible to analyze operational modes of the drilling pump electric motors (Figures 11, 12). It follows from the graphs of Figures 11 and 12 that the operational mode of the drive motor of the drilling pump is one of intermittent operation. The calculation of the equivalent current, as well as direct measurements of the motor temperature give evidence that the pump motor is not utilized in terms of its heating. This is explained by the operating mode of the motor (the technology for driving the wells), the low temperature of the ambient medium and the large time constant for the heating of the machine. For this reason, it was recommended that electric motors with a capacity of 450 KW be used for the drive of the U8-6M pump. The experiments which were performed confirm the possibility and the expedience of this recommendation.

Auxiliary Mechanisms

Numerous mechanisms and coupling clutches for a drilling rig are controlled by means of compressed air. The requisite air pressure is maintained in the tank by controlling the output feed of the compressor station.

TABLE 5

Parameters	Type of Compressor, Electric Motor					
	KT-6, A02-91-8	KSE-5, A91-8	KT-6, A093-8	KT-6, A291-8	AP91-8	KT-6 AP-92-8
Nominal capacity, KW	40	40	40	40	40	55
Nominal current, A	75	81	80	79	94	122
Working current, A	90-105	75	78	130	110	140
Multiplying factor for the starting current level	7	4.5	5.5	7	5.5	6
Multiplying factor for the starting moment	1.1	1.1	1.3	1.1	1.7	1.7
Multiplying factor for the maximum moment	1.7	1.7	2.0	1.7	2.2	2.2
Flywheel polar inertir, kg · m^2	7	7	10.1	7	7	9.2

At the present time, the primary way of regulating the output feed of compressor stations for drilling rigs is the temporary shutdown of the drive motor. However, a stressful repeated short term operating mode of the electric motor with frequent starts is characteristic of this approach, something which has an unfavorable impact on the electrical motor itself and on the control equipment.

Various types of electric motors are used in the compressor drives. Catalog data as well as the current under the actual motor load are given in Table 5. It follows from Table 5 that the load on the electric motors for various compressors runs from 0.9 to 1.7 of the nominal current level at a pressure of 0.7 to 0.8 MPa. The number of starts per hour runs from 10 to 60, while the relative duration of the time the motors are turned on varies in a range of 30 to 80 percent. The electrical motor loads during operation considerably exceeds the nominal values.

The majority of motor failures is a consequence of starting the motors without relieving the compressor load. The resistance moments of both the compressor stations and the electric motors themselves increase during the winter because of the thickening of the lubrication and for other reasons. At this time, the resistance moments frequently exceed the starting moments of the electric motors.

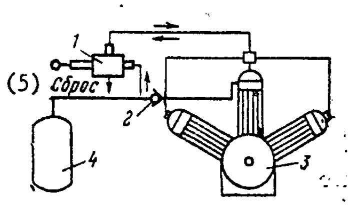

Figure 13. Schematic of the relief valve circuit.

Key: 1. Relief valve;
2. Check valve;
3. Compressor;
4. Tank;
5. Discharge.

The considerable importance of the relative duration of time a compressor is turned on and the frequent actuations of compressors are due not only to the large demand for compressed air, but also to the considerable leaks in a branched air system. Thus, the duration of time a compressor is turned on reaches 30 percent, even in the case where there is not a single mechanism which uses compressed air in operation on the drilling rig. Operational experience has shown that the utilization of high capacity electric motors (55 KW) in the drives of compressors does not yield positive results.

It is expedient to use the KT-6 and KT-7 compressor load relief devices to regulate the output feed of the compressors, i.e., when an air pressure of 0.8 MPa is reached, it is not necessary to disconnect the electric motor from the mains, but rather to shift the compressor over to idle by means of the load relief device. When the air pressure drops down to 0.6 MPa, the valves of the load relief device for the compressor are restored to the initial position, the compressor begins to compress the air, and the electric drive motor is loaded. To provide for such an operating mode, it is necessary to use a special regulating valve.

The air-flow circuit of the compressor load relief valve is shown in Figure 13.

Tests of compressor stations operating in the indicated mode have yielded good results. The use of such a configuration makes it possible to reduce the regulation range of the air pressure from 0.6-0.8 to 0.7-0.8 MPa, something which improves the operational reliability of the mechanisms, controlled by compressed air and significantly facilitates the operating conditions of the electric motor and the control equipment. Calculations show that the equivalent current during motor operation in a repeatedly short term mode is approximately 40 percent greater than the equivalent current level of a motor operating with a relief valve, something which attests to a substantial easing of its thermal loading.

Calculations have shown that despite somewhat of an increase in the expeditures of electrical power, the use of a load relief device has an economic impact amounting to 200 rubles per compressor per year as a consequence of reducing the number of electrical equipment failures and decreasing the expenditures for the repair, replacement and acquisition of spare motors.

The electrical equipment of auxiliary mechanisms is primarily set up on open sites and is subjected to the impact of climatic conditions to the greatest extent. Despite the fact that its failure does not cause long term shut-downs of the drilling rigs, the expenditures related to the replacement, operation and repair of this equipment is quite considerable, if one takes into account the fact that the percentage of electrical equipment failures of auxiliary mechanisms reaches 50 percent of the overall number of failures. This is evidence of the necessity of using KhL design electrical equipment.

Particular attention must be devoted to the parameters of electric motors, especially their starting characteristics, and motors must be used having a multiplication factor of the starting moment of 1.3 to 1.5. The correct choice of lubricant for the bearings promotes an improvement in motor reliability.

Operational experience has also demonstrated the expediency of replacing the magnetic starters of auxiliary mechanism electric motors with alternating current contactors.

CHAPTER THREE. THE ELECTRIC EQUIPMENT OF PUMPING INSTALLATIONS FOR OIL EXTRACTION AND THE PUMP AND COMPRESSOR STATIONS IN A FIELD

General Information

There are three known ways of extracting oil: spouting, pumping and the compressor approach. In the initial operational period of wells, the simplest and least expensive spouting method is used in the majority of cases. Because of the drop in the stratum pressure and in the increase in the water content of the oil pools, the spouting of the wells ceases, and in step with the increase in the working of a field, artificial lifts or mechanized techniques for oil extraction take on increasingly greater significance: using pumps and compressors.

The pump method of oil extraction is basically accomplished by means of deep sucker-rod type pumps and submersible electric pumps. Submerisble centrifugal electric pumps are widely used to pump oil out of deep and high yield wells, where the use of deep pumps with rocker drives becomes difficult.

The percentage of oil extracted in the Eighth Five-Year Plan in Western Siberia by mechanized means amounted to 0.7 percent of total extraction. It increased to 17 percent in the Ninth Five-Year Plan. Wells in areas with deteriorating collector properties or water contamination are being shifted over to mechanized extraction. However, spouting still predominates, as before.

The major drawback to deep pump sucker-rod installations is the installation of the electric drive on the surface and the transmission of the mechanical energy to the pump by means of a long string of rods. At great depths, this causes a significant increase in the stresses in the material of the rods due to their own weight, as well as an increase in the energy losses and limits the delivery of deep pumps (up to 50 m^3/24 hours from a depth of 1,400 to 1,500 m).

Despite the improvement in fluid pump-out modes, the refinement of deep pumps, the design of a standard series of rocker drives, etc., the efficiency of a contemporary deep pump installation nonetheless amounts to 40-60 percent overall. A specific operational feature of sucker-rod pumps in the Western Siberian fields consists in the complexity of the rocker drive structures with heavy foundations on weak, peaty soils, and in the massive application of directional drilling, as a result of which, the sucker-rod pump and the set of rods operate under difficult conditions.

A characteristic feature of the development of Western Siberian fields is the implementation of a system for maintaining a constant stratum pressure right from the start of industrial operation. The discovery of new deposits with a relatively high formation energy, which can be developed with a large number of highly productive wells, and the widescale use of modern techniques for maintaining formation pressure by means of water-flooding has lead to a sharp increase in the number of wells with high liquid yields. For the purpose of increasing the petroleum extraction and improving the final petroleum output coefficient of the formations, water flooding is usually accompanied by forcing the removal of liquid from the water flooded wells. For this reason, there is a rather large group of wells available at the present time with artificial fluid lifting, the yields of which are measured in hundreds and even thousands of cubic meters per 24 hours. Such rapid liquid removal is possible only by means of high performance centrifugal submersible electric pumps and the gas lift technique.

In the majority of Western Siberian oil fields, the sites are drilled by the multiple controlled and controlled directional drilling method. More than half of all the wells are oblique controlled wells, with a deviation of the bottom from the vertical down to 1,500 m by 10 m with a curviture on individual sections of up to two degrees. The significant increase in the number of wells drilled to depths below 2,000 m, and multiple directional and controlled directional wells with a large deviation angle is likewise responsible for the rise in the use of submersible electric pumps with mechanized extraction.

The widescale application of centrifugal electric pump installations is due to many factors. The primary one of them is the installation of the drive directly in the well near the pump, something which eliminates the long coupling assembly between them existing in sucker-rod deep pumping installations. One of the limitations on the useful power delivered to the pump is thereby removed. The increase in the pressure head and the suspension depth of the pump sharply reduces the permissible useful power of sucker-rod pumps and has practically no influence on the ultimate useful power of electric centrifugal pumps.

The increase in the useful power of a deep electric centrifugal pump and its drive over sucker-rod pumps makes it possible to extend the range of pump operation in terms of the amount of lifted liquids at small and intermediate pressure heads (up to 1,500 to 2,000 m). At intermediate and high liquid pressure heads, centrifugal electric pump installations are the most economical and the least labor intensive kind of equipment for servicing for the extraction of petroleum from wells as compared to compressor extraction and lifting the liquids with sucker-rod pumps. In the case of a large delivery, the power expenditure for their installation are relatively small. In this case, its efficiency is rather high (reaches 0.2 to 0.3).

It is not difficult to service the installation, since only the control station and the transformer are placed at the surface. Moreover, the equipment installation and shifting of the wells over to the pumping station are substantially simplified, since no foundation is required for the relatively light control stations and the transformer. Moreover, the period between repairs of the submersible centrifugal electric pumps, according to the data of the Main Tyumen' Oil and Gas Administration, averages 280 days, while for sucker-rod pumps, it is 244 days. The dynamics of the well working equipment by mechanized extraction methods, according to the Main Tyumen' Oil and Gas Administration, are shown in Table 6.

TABLE 6

Allocation of Mechanized Extraction Wells, in Percent	Years 1971	1972	1973	1974	1975
Submersible centrifugal electric pumps	85	85	81	75	68
Sucker-rod pumps	15	15	13	10	10
Gas lift installations	-	-	6	15	22

Submersible Electric Pump Installations

The major oil deposits in the fields of Western Siberia are being developed with submersible electric pumps. The introduction of submersible electric pumps started in 1969.

The transition to mechanized extraction with submersible electric pumps in the oil fields of Western Siberia was related to the lack of submersible pumps with a delivery of more than 500 m^3/day; a lack of electric motors and cables designed for operation in high temperature oil formations; transformers and control stations of the KhL design; modular complete equipment packages of a high degree of plant readiness for the surface electrical equipment; as well as a lack of devices for heating the cable on the drum when it is rewound during hoisting and lowering operations.

A substantial drawback to the power supply circuit for centrifugal electric pumps is the double transformer voltage. While in the old oil regions, double transformation made sense, since a voltage of 0.4 KV was fed to a well (6/0.4 KV substations were installed for a group of wells), in the Western Siberian fields, where a voltage of 6 KV is fed to each well, the use of such a circuit configuration was technically unjustified. In the Western Siberian oil fields, submersible electric pumps operate in individual wells or in wells combined into groups.

The following types of pumps have found application in the fields of Western Siberia:

Type of Pump	Type of Motor	Type of Pump	Type of Motor
ETsN-5-40-1400	PED-20-103	ETsN-6-160-1100	PED-35-123
ETsN-5-80-1300	PED-28-103	ETsN-6-250-1050	PED-75-123
ETsN-5-130-1200	PED-40-103	ETsN-6-350-650	PED-46-123
ETsN-5-200-800	PED-40-103	ETsN-6-350-850	PED-75-123
ETsN-6-100-900	PED-17-119	ETsN-6-500-750	PED-100-123

Prototype UETsN-6-1000-700, UETsN-6-100-650 and UTsEN-6-1400-650 pumps with deliveries of 1,000 and 1,400 m^3/24 hours have been fabricated and are undergoing industrial tests at the present time.

Multiple drilling with an offset of the shaft of the well of up to 1.5 km along the horizontal is widely used in the Western Siberian fields because of the bogginess of the sites. A submersible electric pump is lowered into the well in a string of pump-compressor pipes, to which the submersible cable is fastened over the entire length. When lowering the string into an inclined well, mechanical damage to the cable is frequent. For this reason, submersible electric pumps have been developed which can be lowered into wells on a cable-wire rope (the ETsNB-6-250-800 and ETsNB-5A-250-1050 installations). These installations have undergone industrial tests and are being successfully operated in the Yuganskneft' NGDU [not further defined]. They allow for the possibility of replacing the pump without shutting the well down and curtail the time for lowering and hoisting operations.

In the case of oil extraction with submersible electric pumps, the complete equipment package for one well, regardless of whether it is included in a group or is an individual well, consists of a submersible pump with the electric motor, a control station, a $0.4/U_{motor}$ autotransformer and a submersible cable. Transformer substations at 6/0.4 KV (KTP) [(complete transformer substation packages)] with a capacity of up to 160 KVA are used to power individual wells. The Minsk Electrical Equipment Plant manufactures KTP's for outdoor installations especially for the oil extraction industry ("ND" index). Substations are the most suitable for the electric power supply to individual wells, since they do not require complex construction and installation work, while their capacity is sufficient to power any of the pumps being used. The complete transformer substation packages are not manufactured in a KhL design, something which reduces their reliability when operated in the regions of Western Siberia. The major drawback to the KTP's is the separate delivery of them and the equipment complement for the well and the necessity of a separately heated room for the control stations and the autotransformer.

Complete transformer substations with capacities of 250 to 630 KVA are installed at multiple wells. Because of the lack of special KTP's, substations of various types of a general industrial design are used. The KTP should have a large number of lines for a current of 100 to 200 amps on the 0.4 KV side (according to the number of wells in the group).

The capacity of a KTP is chosen based on the sum of the capacities of the submersible motors of a group. The control stations and the $0.4/U_{motor}$ transformers, which are supplied in complete packages with the pump installations, are housed in heated rooms and connected via cable lines to the KTP. These KTP's have the usual drawbacks: a nonindustrial construction method, the failure to deliver the equipment as a complete package, double transformation of the voltage, and the number of outgoing 0.4 KV lines is insufficient to power groups with a large number of wells.

The following transformer substations have been developed in a KhL design for Western Siberia:

--With transformers having a capacity of 63 to 400 KV, at a voltage of $6/U_{motor}/$ /0.4 KV for individual wells;

--With transformers having capacities of 400 and 630 KVA at a voltage of 6/0.4 KV for a group containing up to seven wells;

--With transformers having a capacity of 1,600 and 2,500 KVA, at a voltage of 35/6 KV for a group containing up to 25 wells.

The technical data for KTPPN substations with capacities of 63 to 400 KVA are given in Table 7. The KhL design KTPPN 63 to 400 KVA substations are equipped with triple windings TMTP transformers at a voltage of 6 U_{motor}/0.4 KV. In this case, double voltage transformation is precluded and there is no necessity for separate autotransformers or 0.4/U_{motor} transformers. All of the equipment of a KTPPN substation, including the motor control station, is housed in a heated unit made at the factory. The foundation is installed at the installation site and the external conduits are connected. There is no need for any additional rooms to house the equipment.

A control station with the KVV-6/320 vacuum contactor has been developed for the KTPPN substation, which provides for manually turning the motor on and off, the capability of automatic self-starting following a short term interruption in the electrical power, the capability of remotely turning the electric motor on and off from the dispatcher center and remote signaling. Provisions are made in this station for protecting the electric motor against overloading and the disconnection of the pump installation when the liquid delivery by the pump is broken off. The insulation of the motor--cable system is continuously monitored, with the disconnection of the motor when the insulation resistance drops below 30 Khoms. The KTPPN room is equipped with an electric heater which is automatically turned on by temperature and humidity sensors.

The PMTP transformer is chosen as a function of the motor power:

Type of Transformer	Type of Submersible Electric Motor
TMTP-1-63	PED-14, PED-17
TMTP-1-100	PED-28, PED-40
TMTP-160	PED-55, PED-75
TMTP-200	PED-65, PED-90
TEMTP-1-250	PED-100
TMTP-400	PED-180

The KTPPN substations can also be used for multiple wells. In this case, the number of them is equal to the number of wells in a group, equipped with

TABLE 7

Type of Substation	Type of Trans-former	Center Stage Voltage, Volts
KTPPN 1-63	TMTP 1-63	360-380-400-420-440-460-480-500-520-540
KTPPN 2-63	TMTP 2-63	645-665-685-705-725-745-765-785-805-825
KTPPN 1-100	TMTP 1-100	790-833-376-919-962-1005-1048-1091-1134-1177
KTPPN 2-100	TMTP 2-100	530-667-604-641-678-715-752-789-826-863
KTPPN 3-100	TMTP 3-100	1230-1270-1310-1350-1390-1430-147-1510-1550-1590
KTPPN-160	TMTP-160	750-790-832-873-914-956-996-1037-1036-1119
KTPPN-200	TMTP-200	1800-1849-1898-1947-1996-2045-2094-2143-2192-2241
KTPPN 1-250	TMTP 1-250	900-934-968-1002-1036-1070-1104-1133-1172-1206
KTPPN 2-250	TMTP 2-250	1700-1758-1816-1874-1932-1990-2048-2106-2164-2222
KTPPN-400	TMTP-400	1820-1868-1916-1964-2012-2060-2103-2156-2204-2252

Note: For all of the indicated substations, the voltage on the high side is 6.3 KV, and on the low side, 0.4 KV

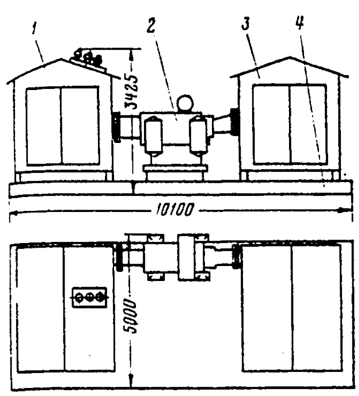

Figure 14. A complete KTPPN transformer substation unit.

Key: 1. 6 KV switchgear;
2. 400 (630) KVA transformer;
3. 0.4 KV switchgear and the control station for the submersible electric motors;
4. Frame.

submersible pumps. All of the KTPPN substations are connected via taps to one 6 KV supply transmission line.

The KTPPN-400 KhL1 and KTPPN-630 KhL1 substations have been developed for the electric power supply to groups of wells. The complete KTPPN-400 KhL1 and KTPPN-630 KhL1 transformer substation packages consist of the TME power transformer unit with a capacity of 400 or 630 KVA, a heated high voltage container type compartment with a service corridor and a low voltage container type heated compartment with a service corridor. The high and low voltage compartments are installed on one prefabricated base with the power transformer. General industrial devices which are housed in heated compartments are used in the KTPPN substations.

The following equipment is installed in the high voltage compartments: the high voltage open wire entrance; a cabinet with the VMP-10-630 oil filled switch; the RV-16/400 disconnector; the PK-6/7.5 and PKTU-10 breakers; NOM-6 voltage transformers; TM-25 KVA. 6/0.4 KV transformer for internal power requirements; a type ShGS heating control panel; a type KVU-66-3 power supply; and a cabinet with a TBS-3-01 transformer to supply power to the 36 volt socket connector.

From three to seven type ShGS-5072 control stations, an entrance cabinet with automatic AVM-10SV or AVM-4NV cutoff switches, a type ShGS heating control panel and TBS-3-0.1 transformer and photoelectric relay cabinets are installed in the low voltage compartment.

During the winter, the KTPPN substation can be turned on only after turning on the electric preheating and heating. Both automatic and manual control are provided for the room heating. The electric heating system provides for a temperature of no less than -20 °C inside the KTPPN during the winter as well as forced electrical preheating with an operating time of 0.25 to 1.5 hours to preheat the equipment and remove icing from the contacts. A provision is made for the connection of three-phase and single-phase consumer equipment to the KTPPN by means of a plug connector for the underground repair of wells. The outside lighting of the KTPPN's is turned on and off automatically depending on the illumination. Meters for the active and reactive power are installed in the low voltage compartment. The following interlocks are provided in the structural design of the KTPPN on the high voltage side:

--Interlocking which does not allow for turning the disconnector on or off when the entrance cutout switch is turned on;

--Interlocking which does not permit movement of the moving elements from the working position to the monitor position, as well as from the monitor position to the working position when the AVM automatic cutout switch and the VMP-10-630 cutout switch are actuated;

--Interlocking, which does not allow for turning on the cutout switch when the moving element is positioned in the gap between the working and monitor positions;

--Interlocking, which does not permit shifting the moving position to the working position when the grounding disconnector is actuated.

There are interlocks on the low voltage side which preclude the possibility of actuating the cutout switch when the door to the switch cubicle is open, which provides for the disconnection of the cutout switch when the door to the switch cubicle is open. A general view of a KTPPN substation is shown in Figure 14, while a single line schematic is shown in Figure 15.

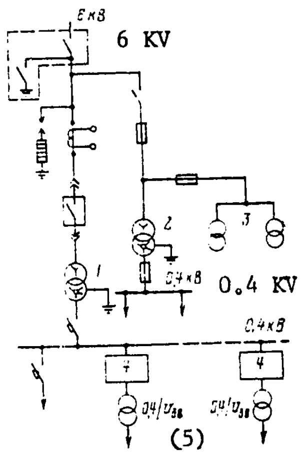

Figure 15. A single line schematic of a type KTPPN-KhL1 transformer substation.

Key: 1. 400 (630) KVA transformer, 6/0.4 KV;
2. 25 KVA, 6/0.4 KV transformer for internal power requirements;
3. NOM-6 voltage transformers;
4. Control stations for the submersible electric motors;
5. $0.4/U_{motor}$.

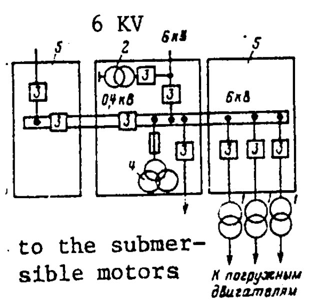

Figure 16. Circuit configuration for the electrical power supply to multiple wells from a UKRUPN-6-KhL1 distribution switchgear unit.

Key: 1. Transformers for $6/U_{motor}$ [KV];
2. 6/0.4 KV transformer;
3. Packaged switchgear cubicle;
4. Voltage transformer;
5. 6 KV distribution switchgear units.

The UKRUPN-6-KhL1 (Figure 16) 6 KV switchgear will be used to supply electrical power to groups with a large number of wells (up to 25) equipped with submersible motors having a capacity of more than 100 KW. Switchgear has been developed to supply electrical power to multiple wells in the Samotlor field and consists of individual plant manufactured units. Complete switchgear package cells for indoors excavator type installation having smaller dimensions than other types of units, are used in the 6 KV distribution switchgear. The entrance cells of the complete distribution switchgear package, the cubicles for the internal power load transformers, the voltage transformers, the dischargers, the outgoing lines and the sectional cutout switch are installed in the entrance unit. Only the outgoing line cells to power the submersible motors using a block unit--transformer--motor circuit configuration are housed in the other block units. All operations involving manually, automatically and remotely turning the motors on and off, including disconnection in the case of the actuation of the protection, are accomplished by means of the cutout switch in the complete switchgear package cell. The control stations for the motors, specially designed for the UKRUPN-6 KhL1, do not have disconnect apparatus in the power circuit and operate in conjunction with the cutout switches of the complete distribution switchgear package cells. The $6/U_{motor}$ KV transformers for the submersible motors should be adapted for outdoor installation outside the UKRUPN units. It is planned that the UKRUPN-6 KhL1 6 KV switchgear units will be universal and can be used as independent units, i.e., when powering multiple wells via one or two 6 KV power transmission lines, or incorporated in the SKTPPN 35/6 KV substation in the KhL design, which should be developed especially to provide electrical power to groups of wells from the field 35 KV distribution network.

A special feature of the electric power supply for multiple wells consist in the fact that the changeover of the wells to mechanized extraction is accomplished over a period of several years. It is not expedient to install 6 KV switchgear immediately at the full capacity of a group. In the initial stage of setting up the field equipment, the drilling rigs and other electrical loads of a temporary nature are powered from the substation. Working from this, the 6 KV switchgear is built up from block units. The first to be installed is the entrance unit, in which there are also three outgoing lines. In step with the changeover of the wells to mechanized oil extraction using submersible pumps, blocks of outgoing lines are connected to the entrance unit, and where necessary, there is a second entrance unit. A provision is made in all units for the installation of electric motor control stations which provide for the same types of protection and protective responses as the ShGS-5072 stations.

Deep Sucker-Rod Pump Installations

Deep well sucker-rod pumps are used for oil extraction in the fields of Western Siberia.

Of the nine basic types of rocker pump drives, only two are used with asynchronous short-circuited electric drive motors of the standard series of types AO and AO2, AOP, AOP2 and AOP2VMS (moisture and freeze resistant design [indicated by final three letters: VMS]).

The rocker drive motors are controlled by means of the series produced BU-3M, BU-4M and BU-5M control units, which provide for individual and group self-starts following the restoration of lost power.

Electric power is supplied to individual wells and groups of wells equipped with deep sucker-rod pumps from the field mains at a voltage of 6 (or 10) KV. A 6 (10)/0.4 KV substation is set up at each well or group of wells. At the present time, complete transformer substation packages of a general industrial design of both domestic and foriegn manufacture are used as the substation.

A standard series of complete substations has been developed to provide power to the motors of the rocker drive. The control units are housed in these substations.

Variable Drive for Pumping Installations

The optimization of the liquid removal mode from wells is an important problem in pumped oil extraction. The necessity of providing for various rates of liquid removal from wells is determined by a number of factors which arise when operating pumping installations. Some of these problems can be solved for sucker-rod deep well pumps by changing the length of plunger travel of the pump or the number of strokes by means of interchangeable pulleys on the shaft of the drive motor; for submersible nonsucker-rod installations, this can be accomplished by choking down at the mouth of the wells or by changing the parameters of the centrifugal pumps. These methods are labor intensive, not economical and entail the necessity of shutting down the pumps for a long downtime.

The conditions under which liquid is pumped wells can be changed by using variable electric drives for the deep pump and nonsucker-rod centrifugal installations.

Various controlled electric drives [2] with a short cycle operational mode based on a dual speed asynchronous motor with a variable ratio between the operational periods at the high and low speeds are used for sucker-rod pumps; in the direct current case, thyristors or a generator-motor configuration is used; alternating current chokes are also used. It is also possible to employ variable electric drives with frequency control and asynchronous rectifier stages.

A real possibility for centrifugal submersible nonsucker-rod installations is the design of a frequency controlled electrical drive. Technical and economic calculations of techniques for mechanized operation of wells in Western Siberia, developed during 1973-1980, have made it possible to establish that it is expedient to equip only 13 percent of the total number of wells having mechanized oil extraction with sucker-rod deep pump installations and 60 percent with submersible centrifugal pumps. In this case, sucker-rod pumps are recommended for well outputs of less than 70 m^3/day while submersible centrifugal pumps are recommended for outputs of more than 40 m^3/day.

The fraction of such wells in Western Siberia is 10 percent and 75 percent respectively. The relatively small number of wells with sucker-rod deep pump installations, the rather high stability in the yield of the wells, the large operational period between repairs of plunger pumps, the small number of wells with an elevated sand content as well as the striving to simplify the drive system of the rocker drives as much as possible, which is due to the natural climatic conditions, have predetermined the use of only the unregulated electric drive for submersible sucker-rod pumps.

The most promising method for increasing the maximum parameters of electrical centrifugal pumps is that of increasing the rotational speed of the pump shaft by means of using a frequency controlled electric drive. An important advantage of a unit with such a drive is the capability of standardizing the pump equipment. The 27 standard electric centrifugal pump dimensions which have been put in production by industry can be replaced with five standard sizes. In this case, the basic pumps will allow not only for an expansion of the area of application of all of the series produced pumps, but also provide for more efficient regulation of the pressure

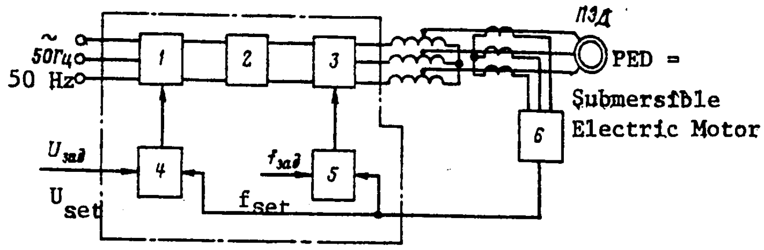

Figure 17. Block diagram of a frequency regulated electric drive for a submersible pump.

head and the delivery in accordance with well parameters. The possibility of reducing the number of submersible centrifugal pumps with a frequency controlled electric drive can be utilized not only when regulating the parameters, but also during pump operating under difficult conditions. The use of such installations in deposits with a heavy aggradation of mechanical impurities will promote an increase in the period between repairs of the pump. This method is most acceptable in the fields with a high formation pressure. where pump delivery heads are needed which are significantly less than the nominal. In this case, the parameters of the selected pump should be knowingly made to exceed the possible liquid removal and they should made to match a reduced power frequency for the motor of down to 30 to 40 Hz.

It has been established on the basis of research that the most optimal frequency control range for the shaft rotational speed of an electric centrifugal pump is 1,800/4,200 r.p.m., which corresponds to a frequency of 30 to 70 Hz.

The frequency controlled electric drive for electric centrifugal pumps, developed in the Tyumen' Industrial Institute, contains a TPCh-40 frequency converter with a DC circuit, an ATS 3x20 autotransformer, a submersible PED-10 electric motor, as well as control and protection units. A block diagram of a frequency controlled centrifugal pump is shown in Figure 17. The major components of the frequency converter are the independent inverter 3 designed around thyristors, the controlled thyristor rectifier 1 with filter 2, the inverter frequency control unit 5, the rectifier control unit 4 and the protection unit 6. The circuitry makes it possible to maintain the nominal voltage across the motor terminals both during starting and in the steady-state mode at any frequency. The given condition is automatically met by the thyristor frequency converter when controlling the voltage as a function of frequency based on the nominal governing law, with compensation for the voltage losses in the current conducting cable; the voltage across the motor terminals is set in accordance with requisite useful power. When starting the motor at reduced frequencies, the starting moment is increased and the starting current level is reduced as compared to starting at the nominal supply voltage frequency. To obtain an economic operating mode for a submersible type PED motor with frequency control, it is desirable to use two different control functions:

control downward from the nominal frequency and control upward from the nominal frequency.

Stand and field tests of the frequency controlled electric drive, performed in the Shaimneft' NGDU, have confirmed the efficiency of the pump parameter control in a wide range and thus the possibility of curtailing the requisite products list of eleectric centrifugal pumps.

The frequency control technique opens up great possibilities in the study and mastery of pumped wells. A mobile research laboratory with a complete sets of instruments, equipped with a thyristor frequency converter, makes it possible to obtain the needed volume of information in a wide range of variation in the output yields to determine an efficient operational mode for a well.

Pumping and Compressor Stations within a Field

Pumping stations are used in oil fields in the system for collecting oil from the groups of operating wells and pumping it to preparation facilities: final pumping stations (DNS) and for pumping the oil with the water removed from the preparation facility to the central product depots: the external transpumping stations.

Pumping stations within oil fields are designed for pumping oil over short distances (5 to 30 km). The pump units of DNS's and the external transpumping stations have similar equipment, for example, the following equipment is incorporated in DNS-13 of the Samotlor field:

--Pump units for pumping oil; one TsNS 300-240 pump with an asynchronous motor having a capacity of 320 KW at a voltage of 6 KV of an explosion-proof type VAO design is installed in each of four pump units; each pump unit has an electrically driven ventilating fan, electrical lighting, pushbutton controls for the main motor and the fan. All of the electrical equipment is explosion-proofed;

--A reagent management unit, in which two reagent dosage pumps are installed having a type VAO electric motors with a capacity of 12.27 KW each, as well as two pumps for feeding the reagent solution into the oil pipeline for the oil with the water removed having VAO-5-2 electric motors with a capacity of 10 KW each and electric heaters for heating the reagent;

--A modular air compressor unit designed for providing compressed air to the pneumatic system and the KIP [control and measurement instruments]; three air compressors with electric motors having a capacity of 10 KW each, as well as equipment for cleaning and drying the air and electric heaters are housed in the unit. The design load of the compressor station is 28 KW;

--A pumping station for repumping the cleaned drain water to the group pumping station, which has two pump units with electric motors of 75 KW capacity each;

--A foam generating station for the automatic fire extinguishing system with an installed electrical equipment capacity of 260 KW powered via two independent 0.4 KV entrances;

--A transformer substation in a 6 x 9 m room; the enclosure for the building structure consists of heated metal panels, hung a metal frame; a 6/0.4 KV complete transformer substation package with a capacity of 2x400 KVA and control station panel for the power to all electrical power consumers at a voltage of 380/220 volts are housed in the building; a separate enclosed transformer substation in accordance with existing standards is placed at a distance of 40 m from the tanks and separators and at a distance of no less than 15 m from other explosion hazardous installations.

Pumps for pumping out trapped oil, condensate and production discharges are installed in the underground tanks on the DNS site: five pumps in all with an overall motor capacity of 71 KW. Also included among the electric power consumers of a DNS are the electrical control panel metering and measurement instruments, exterior lighting installations, the electrically powered gate valves on the oil pipelines and 33 electric motors for various purposes. The overall installed capacity of all electric power recipients is 1,930 KW.

Pumps with electric motors having capacities of 75 to 200 KW at a voltage of 0.4 KV and capacities of 250 to 630 KW at a voltage of 6 KV are used for all of the DNS [final pumping stations] in the pump units for oil repumping, depending on the requisite delivery and pressure head of the pump. Electric motors with capacities of 500 and 630 KW have built-in electric heaters, which are automatically turned on when the pump shuts down.

The same unit construction is used for all types of pumps. The frames of the units are metal, welded frames; the enclosure structures are fabricated from heated metal panels. The equipment is installed under plant conditions and delivered to the construction site of the DNS in assembled form by any means of transport. The units for the completely packaged prefabricated pumping centers and oil preparation installations have the same structural design. That same modular and complete plant readiness principle is used for water pumping stations, for example, for the cleaned sicharges at group pumping stations.

The number of pump units in a DNS can vary. Thus, the pumping station of the Agansk field with a delivery of 1,200 m^3/hr consists of five units (one of them is a back-up), while the KSP-10 pumping station of the Samotlor field, which is designed for a delivery of 3,900 m^3/hr, has 16 units (three of them are back-ups). The unit is delivered with 8 MS-7 pump set-up and installed with an asynchronous explosion-proof type VAO electric motor having a capacity of from 320 up to 500 KW at a voltage of 6 KV (depending on the number of pump rotors).

Included among the auxiliary electrical equipment of final pumping stations are the electrified gate valves on the oil pipelines and tanks with electric motors with a power rating of up to 7.5 KW, air compressors for the pneumatic automation systems (10 KW), pumps for pumping out condensate in trapped oil (13 KW), fire extinguishing pumping systems, etc. The overall design load of the 0.4/0.23 KV electrical power consumers amounts to 200 to 400 KW.

Compressor stations are used in the oil fields of Western Siberia to transport byproduct natural gas to gas refineries and to the Surgutskaya GRES. The compressors usually have a gas engine drive. Thus, the compressor station in the product depot of the Western Surgut field, which is intended for delivering the gas of the Ust'-Balyk and Western Surgut fields to the Surgutskaya GRES, is equipped with nine 10 GKN compressor plants with a gas engine drive having a power of 1,500 hp each.

Compressor stations with a gas motor drive are used in the gas lift method of oil extraction in the Pravdinsk field and serve for feeding gas to operational wells. Electric drive for compressor stations used for the auxiliary mechanisms (ventillation fans, water supply pumps, oil lubricating system, etc.).

Auxiliary Mechanisms at Compressor Stations

	Number of Electrical Devices	Total Installed Capacity, KW
Production process pumps for the lubrication system, cooling, air drying, gas coolers, etc.	12	108
Air compressors for the starting air and the monitor and measurement meters	3	82
Ventillation	8	53
Boiler facility using gas fuel	7	14
Water supply and sewerage system	5	40
Electric lighting	-	40
TOTAL	35	337

CHAPTER FOUR. THE ELECTRICAL EQUIPMENT OF THE INSTALLATIONS OF THE FORMATION PRESSURE MAINTENANCE SYSTEM

General Information

Boundary contour water flooding is used in the Western Siberian fields for sustaining formation pressure (PPD) [(formation pressure maintenance)]. The group pumping station (KNS) served to pump water into the productive strata; these stations deliver water at a pressure of 15 to 20 MPa via water pipelines to the injection wells. Rows of injection wells are positioned after every three to five rows of operating wells; the spacing between adjacent rows of forcing injection wells amounts to 3.5 to 4.5 km. The injection pressure is governed by the production configuration for working wells. At a pressure of up to 18 MPa for water pumping, TsNS-180-1422 pumps are used and at pressures of up to 20 MPa, TsNS-180-1900 and TsNS-500-1900 pumps are used.

In the initial stage of putting fields in production, when the volume of pumped water is small, water for the PPD system is taken from underground Cenomanian water bearing strata. The water from the water intake wells is fed to the group pumping station by submersible electric pumps having electric motors with capacities of 32 to 250 KW. The Cenomanian water contains gas. For this reason, the gas is separated in separators and it is burned in flares prior to pumping the water to the group pumping stations.

In the second stage, water is supplied to the group pumping stations via

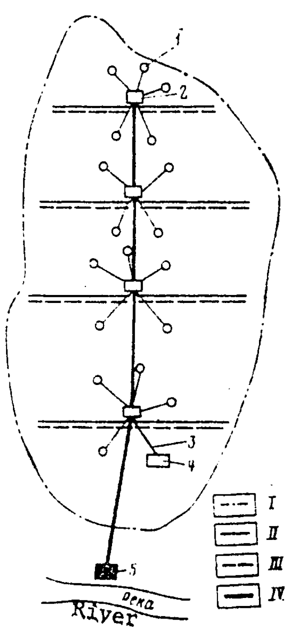

Figure 18. General schematic of a formation pressure maintenance system.

Key: 1. Water intake wells;
2. Group pumping stations;
3. Discharge pumping to the KPS [possible typo for KNS - group pumping station];
4. Oil preparation facility;
5. Water intake;
I. Deposit contour;
II. Injection water line;
III. Row of injection wells;
IV. Main trunk water line.

trunk water pipelines from water intake works, which are located at lakes (with a single lift) and rivers, flowing through the territory of the field (with two lifts).

Combined water intake works can be used for a group of fields located close together, for example, the combined water intake for the Agansk, Vatinsk and Severo-Pokursk fields, located on a branch of the Ob' river.

After the comprehensive oil preparation installations (UKPN) are brought on line, the cleaned discharge water of the UKPN serves as an additional source of water for the formation pressure maintenance system.

The major electric power users of the formation pressure maintenance system are the group pumping stations and the pumping stations of the first and second lifts of the water intake works.

A general schematic of a formation pressure maintenance system is shown in Figure 18.

Water Intake Pumping Stations

The intake water works for the water supply of a formation pressure maintenance system using river water consist of the water intakes, the first and second lift pumping stations and the auxiliary installations. The first lift pumping stations can be permanent above-water, floating and shallow well jet pumps.

The fixed first lift pumping station for the Samotlor field with a water delivery of 180 million m^3/year was installed on a sheet piling in the riverbed. Two frame buildings for the pump facility with a height of 7 m with the enclosing structures of heated metal panels have plan dimensions of 30 x 9 m each. Some 24 type 24A-18x1 pumps with vertical asynchronous electric motors having a capacity of 250 KW each at a voltage of 6 KV are installed in the building of the pump facility. The overall installed capacity of these electric motors is 6 MW and that of the auxiliary equipment is 160 KW at a voltage of 0.4 KV.

The auxiliary electric equipment at a voltage of 0.4 KV (electric heating, electric lighting, ventillation, etc.) is supplied from a two-section station control panel. In order to provide the requisite reliability in powering the 0.4 KV loads, two transformer substations at 6/0.4 KV are provided, which are mounted on a pier. The pier is intended for coupling the pumping station to the shore, for transporting the equipment, running the water pipelines and other conduits. In particular, 66 power and monitor cables at a voltage of 6 and 0.4 KV are run along the pier.

The electric motors with a capacity of 250 KW are powered from the combined 6 KV distribution switchgear located on shore, close to the second lift pumping station.

First lift floating pumping stations are used for small output water intakes. A floating pump facility takes the form of a metal pontoon with a superstructure made of heated metal panels. Some three units with 300D90 pumps and electric motors with a capacity of 100 KW each, auxiliary equipment, a 0.4 KV distribution panel and type ABN automation equipment are installed in the superstructure. The output of such a pump facility is 20 million m^3/year. A floating pumping station is transported in assembled form via the river from the manufacturing plant to the construction site of the water intake.

A basic electrical schematic of a floating pumping station for the first lift is shown in Figure 19. The local automation system for the pumping station, based on ABN equipment, provides for the possibility of automatically starting the backup pump in the case of an emergency shutdown of the working pump, self-starting the working pumps after a short term interruption in the electric power, automatic control of the gate valves during the starting of the pumps and automatic control of the electric heating.

The water intake lines from the floating pumping station have flexible inserts, so that the pontoon with the pumping station moves vertically in accordance with the fluctuations of the water level in the river. Electric power is fed to the pumping station from a 6/0.4 KV transformer substation, installed on shore, and is fed via flexible cables in a rubber jacket.

Floating pumping stations should be protected against ice-jangs, and should have guiding pile foundations for moving vertically. It is perdically necessary to clean the ice off of them in the winter. Pumping stations with jet pumps are free of these deficiencies. Pontoons with jet pumps are secured to the bottom of the river on a prepared base. The jet heads are connected by water pipelines to the drive pumps, which are located on the shore above the water level along with the second lift pumps. The drive pumps force the water to the jet units and the energy of the water flow is imparted to the water sucked up from the river.

The kinetic energy of the total flow is converted to the static pressure head needed to produce the requisite pressure at the intake to the second lift pump. All of the electric power equipment of the pumping station with jet pumps is located on shore along with the electrical equipment of the second lift pumping station, close to the power source: combined 6 KV switchgear.

Only a block modular design is used for the second lift pumping stations as well as the drive pumps for the jet units. The pumping units are assembled into blocks at the manufacturing plant, where these blocks consist of a framework or a pontoon with the enclosure structures made of heated metal panels. From one to six pump units are installed in a single block, depending on the type of pump and electric motor.

Synchronous motors with a capacity of 2,500 KW and asynchronous motors with capacities of 200 to 1,600 KW at a voltage of 6 KV are used in the second lift pumping stations. Some 15 motors with a capacity of 250 KW each, three motors with a capacity of 1,600 KW each and two motors with a capacity of 500 KW each are installed in the combined water intake with jet pumps for the formation

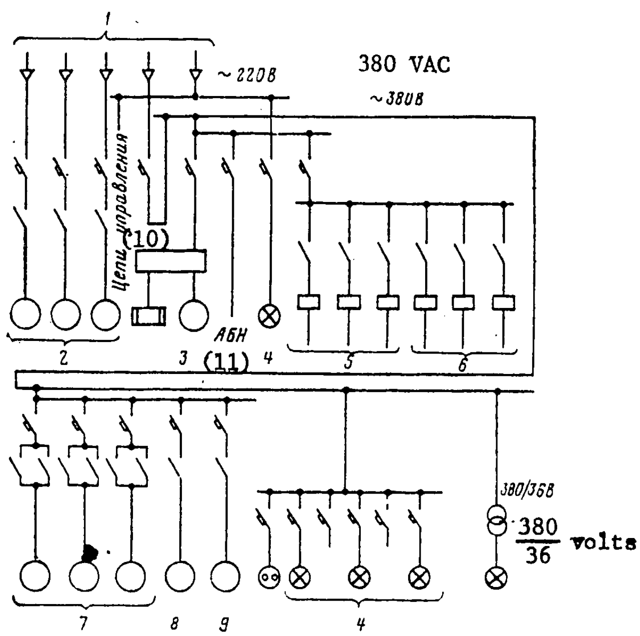

Figure 19. Basic electrical schematic of a first lift floating pumping station.

Key: 1. Input;
2. 100 KW electric motors for the pump drives;
3. Electric air heater;
4. Lighting;
5. Electromagnetic drain valves;
6. Electromagnetic priming valves;
7. 0.6 KW gate valve drive electric motor;
8. 1.7 KW pump drive electric motor;
9. 1.1 KW ventillation fan drive electric motor;
10. Control circuits;
11. ABN [unknown type of automation equipment, probably load control].

pressure maintenance system of the Agansk, Vatinsk and Severo-Pokursk fields. The pump units are housed in seven individual blocks, something which makes it possible to build the water intake in individual stages.

The total installed capacity of the electric power users amounts to 9.9 MW for this water intake. The combined distribution switchgear for the water intake provides power to 20 electric motors at a voltage of 6 KV and two 6/0.4 KV transformer substations. All of the users are powered from two transformer substations at a voltage of 380/220 V (the electric heating, electric lighting, ventillation, etc.). The 6 KV distribution switchgear receives power from a 35/6 KV substation with a capacity of 2 x 10 MVA, located on the site of the water intake, close to the pumping station for the second lift. The control for the emergency and actuating signalling from the ABN equipment of the modular pumping stations is brought out on a common operator panel, installed in a separate room. The display of the readings of the metering instruments for the amount of water being pumped through each water line is likewise brought out on the operator's panel. It is possible to transmit these readings, as well as emergency signals, via remote control panels. A single automatic stage by stage start is provided for all pump units when restoring electrical power after a short term interruption.

Automated Modular Pumping Stations

Modular block group pumping stations (BKNS) with a delivery of 450 m^3/hr using TsNS-180-1422 pumps and with a delivery of 2,100 m^3/hr with TsNS-500-1900 pumps are used to pump water into the productive strata in the deposits of Western Siberia. The TsNS-180-1422 pump is supplied with a 3,000 r.p.m. type STD-1250-2 synchronous motor, while a STD-4000-2 motor with a power of 4,000 KW is used to drive the TsNS-500-1900 pump. The STD type synchronous motors have a brushless excitation system.

The BKNS's are manufactured at the plant for complete modular package equipment (Ministry of Construction of Petroleum and Gas Industry Enterprises) and at the mechanical repair plant in Tyumen'. One pump unit in a complete set with all of the auxiliary equipment (oil pumps, electrified gate valves in the water line, ventil ation fans, electrical heating devices, monitor and measurement instrument sensors and meters) is installed in each pump block.

The BKNS's with the TsNS-180-1422 pumps (plan I) consist of four individual blocks, a 6/0.4 KV transformer block, a control unit and a 6 KV switchgear unit. Each block (with the exception of the 6 KV switchgear) takes the form of a completely finished structure with dimensions in a plan view of 3.25 x 9 m and does not adjoin the other blocks. The 6 KV switchgear unit conists of two boxes with plan view dimensions of 3.25 x 9 m and is assembled in a single room at the installation site for the group pumping station. The dimensions of the transformer block are 3.25 x 6 m. All of the blocks do not exceed the permissible overall dimensions for railroad transportation.

The foundations are built on the installation site of the BKNS and the external conduits are connected (water lines, grounding device cables, communications and remote control lines). Interconnection of the 6 KV distribution switchgear unit is also necessary. The control stations for the pumping units, the control stations for the synchronous motors and the control panels for the auxiliary mechanisms as well as one end of the remote control unit being monitored are housed in the control block.

A BKNS with TsNS-180-1422 pumps of the mechanical repair plant consists of four pump blocks, a control block and a 6 KV switchgear unit. The pump blocks and the control block are assembled without the side walls on the floating pontoons. Each block has plan view dimensions of 4 x 11.4 m, which exceeds the permissible overall size for railroad transportation. For this reason, the BKNS is towed via river transport to the construction site, and is dragged from the river to the site. The pumping blocks and the control blocks are joined together in a single room at the construction site, along with the construction of the foundations and the connection of the conduits. In this case, a common machine room is formed, something which creates more favorable conditions for operation. Such a BKNS has no individual 6/0.4 KV transformer units; the transformer are installed in the control block. The 6 KV distribution switchgear unit consists of two parts (Figure 20), which are assembled on the BKNS construction site. In this case, the frames and the enclosing structures are joined together by bus bridges and monitor cables. The cable connections, which do not pass through the plane of the joint of the blocks, can be installed at the manufacturing plant. This curtails the volume of installation work at the construction site.

A schematic of the electrical connections of a 6 KV switchgear unit is shown in Figure 21. The circuit configuration is composed of type K-XII type KRU (complete switchgear package) cubicles manufactured by the Moscow "Elektroshchit" plant, with an auotmatic standby switching device, using a sectional switch. The 6 KV switchgear has cable entrances. The internal power requirement transformers of the BKNS at a voltage of 6/0.4 KV are connected ahead of the entrance cutout switches. A specific feature of the circuitry is the use of two KRU cells for each motor. A cutout switch is located in one of the cells, and in the other are two voltage transformers which serve to provide power for the brushless excitation system of the motor.

Rectified current, derived from type KVU-66 rectifiers, is used to actuate the electromagnetic drives of the 6 KV cutout switches. Type BPT-1002 and BPN-1002 power supply units serve as the source of rectified operating current. Standard synchronous motor control stations of the PN series are installed in the 6 KV switchgear unit.

A BKNS with TsNS-180-1422 pumps of the complete modular package equipment plant (plan II) consists of four pump units, as well as auxiliary pump units, a control collecting main, 6/0.4 KV transformers and 6 KV switchgear. All blocks have plan-view dimensions of 3.25 x 6 m and they can be shipped by rail transport. The pump blocks and the block of auxiliary pumps are assembled on the construction site. The control unit is set up separately and does not adjoin the other blocks. The 6 KV switchgear unit is built from two halves in a single building with plan-view dimensions of 6.5 x 12 m. Only the KRU cubicles and the KVU-66 rectifier units are housed in the 6 KV switchgear unit. All of the remaining electric equipment, including the control stations, are located in the control block.

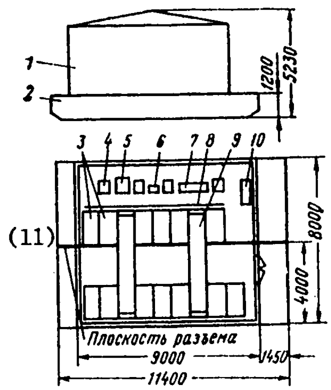

Figure 20. Overall view of the 6 KV switchgear for a BKNS [modular complete pumping station package] with TsNS-180-1422 pumps.

Key:
1. Building for the 6 KV switchgear;
2. Base (pontoon);
3. 6 KV KRU [complete switchgear package] cubicles;
4. Motor control station;
5. Station control panel;
6. Rectifier;
7. Control panel;
8. Partition;
9. Buswork bridge;
10. Electric air heater;
11. Plane of the joint.

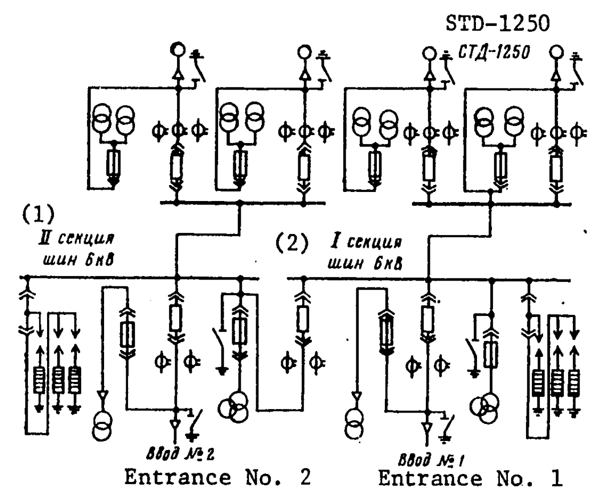

Figure 21. Schematic of the electrical connections of the 6 KV switchgear unit of a modular complete pumping station package with TsNS-180-1422 pumps;

Key:
1. Section II, 6 KV buses;
2. Section I, 6 KV buses.

The BKNS with the TsNS-500-1900 pumps are manufactured only by the mechanical and repair plant and consist of four pump units and service and control units. All of the blocks have plan view dimensions of 4 x 11.4 m and they are moved only via water transport on floating pontoons. All six BKNS blocks are joined together at the construction site into a single building and form a common machine room.

The water cooling pumps for the oil are located in the service unit; the panels with the starting and protective equipment for the auxiliary mechanisms, and the monitor and measurement as well as remote control panels are installed in the control block. The 6 KV distribution switchgear and the 6/0.4 KV complete transformer substation package for providing electric power to the BKNS with TsNS-500-1900 pumps are built in accordance with individual project plans using complete modular equipment packages and structural units.

The layout configurations of the blocks of various types of BKNS's are shown in Figure 22. Artesian wells for fresh water and water intake wells for Cenomanian water belong among the additional structures for a BKNS. The water intake wells are equipped with submersible pumps having PED-32-230 electric motors with a power of 32 KW.

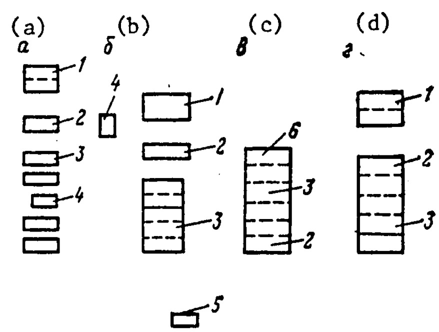

Figure 22. Layout configurations for the units of a BKNS [modular complete pumping station package].

Key: a. BKNS with TsNS-180-1422 pumps (plan I);
b. BKNS with TsNS-180-1422 pumps (plan II);
c. BKNS with TsNS-500-1900 pumps;
d. BKNS of the mechanical repair plant with TsNS-180-1422 pumps;
1. 6 KV switchgear block;
2. Control block;
3. Pump block;
4. Block of 6/0.4 KV transformers;
5. Collecting main block;
6. Service block.

Groups of water intake wells, conisting of three to six wells, can be positioned at a distance of up 500 m from a BKNS. A 6/0.4 KV complete transformer substation package with a capacity of 160 to 400 KV is installed to provide power to the groups of water intake wells. Electric power is supplied to the complete transformer substation package of the water intake wells from a 35/6 KV substation in the case of a group pumping station or from 6 KV distribution switchgear via 6 KV open wire lines for a group pumping station.

The scope of the automation of BKNS's makes it possible to almost completely dispense with attending personnel, which are needed only for the initial starting of the station, in the case of a breakdown or planned preventive maintenance. Relays which are located in the control panels for the units and in the 6 KV distribution switchgear control panel signal the causes of equipment defects. A general (not decoded) emergency signal is transmitted via a wire communications channel from the BKNS remote control set being monitored to the dispatcher control points. Information on the volume of pumped water is transmitted via the remote control channel once every two hours or when interrogated from the dispatcher point.

A set is started automatically after pressing the "start" button on the local control panel. In this case, the oil pump of the lubrication system is first turned on, and when the requisite oil pressure is reached, which is monitored by an electrical contact manometer, the water pump motor and the electrical drive for the gate valve on the injection line are turned on. After the pump is run-up, the protection against a pressure drop in the injection line is also turned on. All of the intermediate operations for an automatic start are monitored by signals at the control station for the unit. After reaching the specified injection pressure, the start is terminated and the unit shifts over to automatic control.

The following protection is provided from the beginning of the start and during normal operation: protection against a drop in the injection pressure, against a drop in the oil pressure, against overheating of the bearings or oil in the end of the oil system, protection of the motor against short circuits (longitudinal differential current protection is used for the STD-4000-2 motor and current cutoff protection is used for the STD-1250-2 motor), protection of the motor against overloading, minimal voltage, against short circuits to ground as well as protection of the motor against asynchronous running. All of the types of protection enumerated above act to disconnect the electric motor. The overload protection can be switched over to be actuated by a signal.

One of the BKNS pumps can be a standby and prepared for automatic starting. In the case any working unit is disconnected by the production process or electrical protection circuitry, the backup set is automatically started. When voltage is lost in the 6 KV switchgear and all of the motors shut down, all of the cutout switches are cut off by the minimum voltage protection devices after 0.5 seconds, since no provision is made for self-starting of the motors. After the voltage is restored on the 6 KV buses, all of the motors are started automatically in sequence, with the exception of the standby, if the electric power interruption time did not exceed 3 to 6 minutes. In case this time is exceeded, the motors can be started only manually. To provide for stable operation of the power system when the frequency is reduced, some of the group pumping station motors are connected by an automatic frequency load relief device. After the frequency is restored, the motors are started automatically in sequence.

The basic control circuit for the STD-4000-2 motor with brushless excitation is shown in Figure 23. Used in the circuit for each motor are three complete distribution switchgear cubicles: with a switch, with current transformers Tr4--Tr9 and with two voltage transformers Tr6 and Tr7. Moreover, a set of current transformers for the differential protection of the motor M is installed in a separate cabinet. The exciter G takes the form of a three-phase synchronous 400 Hz generator. The armature of the exciter is located on the shaft of the motor M and is coupled to the excitation winding of the motor through an uncontrolled diode rectifier, put together in a three-phase bridge circuit configuration. Connected in parallel with the rectifier and the excitation winding of the motor M are two thyristors with discharge resistors and a thyrsitor triggering circuit. The protective thyristor circuitry serves to limit overvoltages across the diode rectifier during starting and in other transient modes. The thyristor triggering voltage is 600 to 900 volts. The rectifier and protective thyristor circuitry are mounted on the shaft of the motor and rotate with it. Since the excitation winding of the excitor is stationary, there is no need for a commutator or contact rings.

Current transformers Tr4 and Tr5 serve to power the excitation winding of the exciter through the excitation regulator, AER, and uncontrolled rectifier D1--D4. An additional excitation source is voltage transformer Tr7, which is connected to rectifier D1-D4.

The additional excitation source provides for stable motor operation in the case of small loads and is used for relay forcing of the excitation. The AER regulator operates on the principle of controlled compounding. During starting and when the motor is overloaded, the regulator provides for parametric excitation forcing [sic]. Additional relay forcing of the excitation when the voltage drops across the 6 KV buses is accomplished by means of relay K16 and contactor K10, which shunts rheostat 1 in the supply circuit for the excitation winding of the excitor from the voltage transformer (Tr7). The automatic excitation regulator provides for automatic regulation of the excitation to maintain the specified power factor and a constant voltage across the motor terminals.

The value of the automatically regulated power factor depends on the setting of the AER [automatic excitation regulation] and can be set in a range of from -0.9 to +0.9. During normal operation (following adjustment), the excitation is controlled and the power factor is set by rheostats R1 and R2. With the action of the motor starting program and when switch B1 is turned on, the motor speeds up asynchronously. After the reduction of the starting current to the value set by relay K2, i.e., as the near-synchronous speed is approached, the armature of relay K4 drops out. After a certain time, equal to the sum of the time delays of relays K4 and K5, contactor K6 is turned on and a voltage is fed to the excitation winding terminals of the exciter. Prior to the actuation of contactor K6,

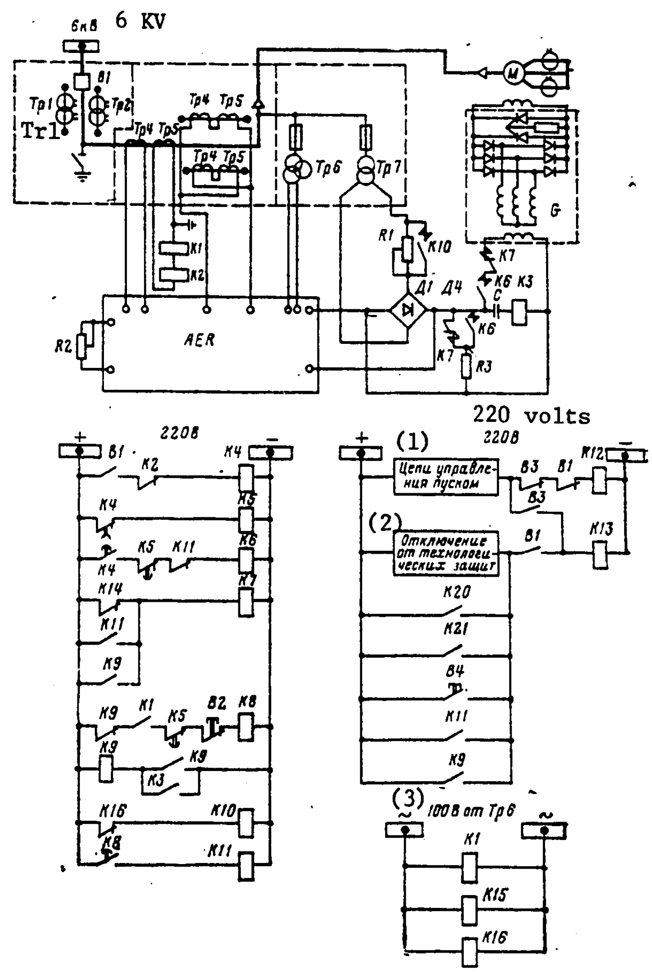

Figure 23. Basic schematic of the control and protection circuitry for a synchronous STD-4000-2 motor.

Key: 1. Starting control circuit;
2. Disconnection from production process protection circuitry;
3. 100 volts from Tr6.

rectifier D1--D4 is loaded into resistor R3 by contactor K7. After the synchronization of the motor, the relay for the reactive power direction K1 is cutoff because of the reduction of the current in the winding, connected to transformer T5 (the voltage winding for relay K1 is connected to transformer Tr6), and breaks the circuit of time delay relay K8.

In the case of long term asynchronous running, power relay K1 remains actuated and with the expiration of the time delay of relay K8; in this case, the following are turned off: switch B1 (K11 is turned off in the circuit of the disconnection electromagnet for K13) and the excitation (contact K11 is turned on in the circuit of the excitaion contactor K6). Where it is necessary to disable the asynchronous operation protection, this can be accomplished by means of pushbutton B2. With the breakdown of one of the diodes of the rotating rectifier, an alternating current flows in the winding of relay K3, which is connected through capacity Z; the contact of relay K3 closes and the switch B1 and excitation winding of the exciter (contactor K7) are disconnected through intermediate relay K9. Production process protection circuitry, the emergency pushbutton B4 and the contacts of relays K20 and K21 also disconnect switch B1 and the excitation circuit. Relay K20 is the output relay of the differential current protection for the motor, the circuits of which are not shown in the schematic. The relay for this protection is connected to current transformers T1 and T2. Relay K21 is the output relay of the automatic frequency load relief circuit. It is inserted in the frequency relay circuit, which is located in the complete switchgear cubicle for the bus voltage transformer. The contacts of relay K21 are closed when there is an emergency drop in the frequency in power system. Contacts B1 and B3 in the circuits of electromagnets K12 and K13 are the blocking contacts for switch B1 and its drive respectively. Relay K15 is the minimal voltage protection relay.

The circuit described here is being used successfully to provide electric power to BKNS's without using reactors. In the case where motors are powered through reactors, the starting voltage is reduced to 55-70 percent of the nominal. The addition excitation source with such a low voltage does not provide for effective excitation, and relay forcing of the excitation does not achieve its goals.

For this reason, when the motors are connected through reactors, a different circuit is used to power the excitation circuits (Figure 24), in which type TBS transformers at a voltage of 380/110 volts are used, which are connected to the local internal power load buses of the 6 KV switchgear through magnetic starters K1. Since the local internal loads of the 6 KV switchgear are inserted ahead of the reactors, the voltage on the 0.4 KV buses amounts to 75 to 90 percent of the nominal. In this circuit configuration, when starting the next sequential motor, the previously started motors operate in a more stable fashion, since effective relay boosting of the excitation is provided for them. The boost relay K16 (see Figure 23), which is inserted after the reactors, actuates immediately when starting the next motor in the sequence because of the considerable voltage drop, while the boost voltage is considerably higher, since the AER is inserted ahead of the reactors.

The circuit in Figure 24 makes it possible to reduce the number of complete switchgear package cubicles and the overall dimensions of the 6 KV switchgear building.

One cubicle with a switch is used to power a motor using this circuit configuration, instead of three KRU [complete switchgear package] cubicles. The current transformers for the excitation system, Tr4 and Tr5, are installed in the current transformer cabinet along with transformers Tr1, Tr8 and Tr9 for the differential protection, with transformer Tr2 for overload protection and transformer Tr3 for protecting against shorts to ground; the overall dimensions of the cabinet are not increased in this case. Miniature panels with type TBS transformers are used in place of cubicles with voltage transformers. One cubicle with the voltage transformers has plan view dimensions of 0.9 x 1.6 meters, while a panel with six TBS transformers and all of the auxiliary equipment is 0.6 x 0.8 m. The circuit of Figure 24 has been used recently in all cases, regardless of the presence of reactors in the 6 KV switchgear.

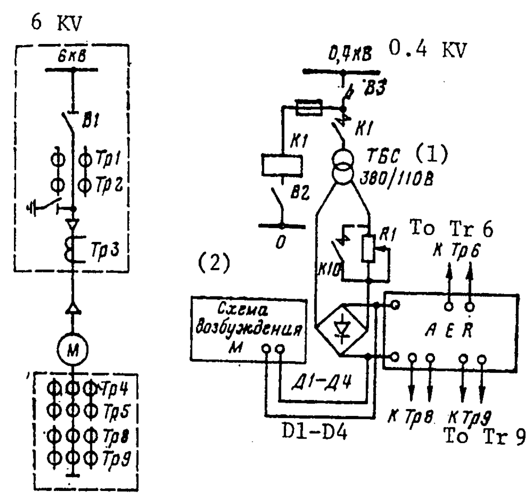

Figure 24. Schematic of the automatic excitation power supply.

Key: 1. 380/110 volt TBS type transformer;
2. Motor excitation circuitry.

CHAPTER FIVE. THE ELECTRICAL EQUIPMENT AND ELECTRICAL POWER SUPPLY FOR TRUNK PIPELINE FACILITIES

General Characteristics of Trunk Pipelines

In the complex and difficultly accessible oil and gas extraction regions of Western Siberia, the major form of long range oil and gas transportation is pipeline transport.

The pressure in a pipeline falls off in step with increasing distance from the oil and gas fields. For this reason, in addition to the head end pumping station, several intermediate pumping or compressor stations are built on long pipelines, where these stations maintain a specified pressure in the pipeline over the entire route. The number of intermediate stations and the spacing between them are determined by calculations and depend on the initial pressure in the pipeline, the profile of the pipeline route, the difference in the altitude level markers for the stations, etc.

On the whole, a trunk oil pipeline contains a head end pumping station, fill stations with the tank farm (intermediate and terminal), intermediate pumping stations, the linear portion or the trunk pipeline itself with the communications link and the devices for protecting against soil corrosion and stray ground currents.

The head pumping stations are intended for receiving the oil from its preparation facilities and transpumping it from tanks into the trunk pipeline. Included in the production process equipment of head end pumping stations are the tank farm, the transpumping station, with a colocated or separate booster pumping station, the pipelines, filter installations and devices for starting the cleaning go-devil.

Included in the complement of production process facilities of the intermediate pumping station are the transpumping station, the pipelines, the filter installations and devices for starting and receiving the cleaning go-devil.

In individual cases, an intermediate pumping station has tanks and pressure support pumps.

In addition to the production process structures at pumping stations, there are also auxiliary facilities which provide electricity, heat and water, the sewerate system as well as rooms for administrative and management services, repair and auxiliary operations.

A transpumping station provides for moving the oil through the trunk pipeline. Some four centrifugal high pressure pumps of the same type, which are connected in series are usually installed in a pumping station. One is a standby. An additional few low pressure support pumps are inserted in the head end pumping station to deliver liquid to the main pumps, if they do not have sufficient suction power. At intermediate pumping stations, when tanks are available to them and with an inadequate suction power of the pumps, pressure support pumps are also installed, but without a backup.

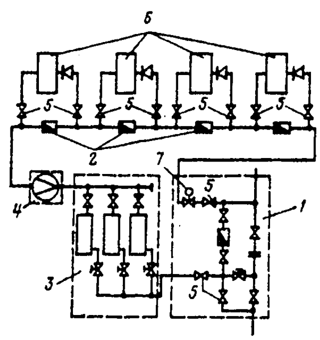

Figure 25. Production process configuration of a transpumping station.

Key:
1. Site for receiving and starting the cleaning go-devil;
2. Check valve;
3. Filters;
4. Sump with orifice;
5. Electrically driven gate valve;
6. Trunk pipeline pumps;
7. Regulating valve.

The piping configuration for pump units is designed so as to provide for the series connection of the pumps through a common collection main with separate check valves. Such a piping configuration for the units makes it possible to start and stop any pump without terminating the operation of the other units, as well as provide for stage by stage regulation of the output of the pumping station by changing the number of operating pumps.

The production process configuration of an intermediate pumping station is shown in Figure 25. The transpumping of the oil is accomplished in the following manner. The liquid being transpumped, after passing through the point for the reception and starting of the cleaning go-devil 1, through filters 3 and the sump with an orifice 4, is fed to the intake of trunk pumps 6. The collector with the check valves 2, the electrically driven gate valves 5 and the regulating valve 7, are, as a rule, housed in the machine room. The collector is located outside the pumping station building while the regulating valves are housed in a special room at the oil transpumping stations of large diameter pipelines. All of the pumps and electric motors are mounted on individual foundation frames.

The auxiliary equipment, which is installed at oil transpumping stations, corresponds to the type of trunk pipeline units and the technological transpumping schemes. Circulation lubrication of the units, convective exhaust ventilation, an air supply system, air cooling of the electric motors of the main pumps, a pump-out system for the collecting sump tanks, and a system for producing excess pressure in the electric motors with a closed ventilation cycle are most frequently encountered.

A modern pumping station for a trunk oil pipeline is a complex, high energy input facility. The installed capacity of the motor at several pumping stations reaches 30 MW.

Since the major oil extraction regions of Eastern Siberia have a well branched, high capacity electric power supply system, electric drives are used for the main and auxiliary mechanisms at all pumping stations of trunk oil pipelines.

Gas transports via trunk gas pipelines is accomplished by using the formation pressure or by means of compressor stations located along the gas pipeline. The head end structures of the gas trunk line are located close to the fields and consist of the gas collection and delivery lines, the installations for cleaning, drying and odorizing the gases, a compressor shop as well as systems for electric power and water supply and sewerage. Where necessary, a head end compressor station is also constructed.

The line facilities consist of the trunk gas pipeline, the stop valves, crossings of natural and artificial obstacles, cathodic protection stations, drainage installations, etc.

Intermediate compressor stations are constructed to maintain the requisite pressure when transporting gas along a gas line. Included in the complement of compressor stations are one or more compressor shops, an electric power station or transformer substation, a water supply system, oil dust catcher installations, installations for oil recovery and other auxiliary equipment.

Compressor stations are used on gas trunk pipelines, which are equipped with gas motor piston type compressors or centrifugal force pumps driven by gas turbines or electric motors.

Gas collection points of a comprehensive gas preparation installation are constructed in gas fields, after which the gas is routed into the gas trunk pipeline.

In the initial period of developing gas fields, the operation does not use compressors; a head end compressor station is brought on line later.

At the present time, the northern Tyumenskaya oblast has still not been provided with a high capacity electrical power supply system. For this reason, gas turbine plants are used to drive the main mechanisms of compressor stations. The auxiliary equipment of comprehensive gas preparation installations and compressor stations has electrical drives though. The electrical power for this equipment, as well as the electrical automation, control and lighting systems is provided from transformer substations, which are powered from transportable automated type PAES electric power stations or from their own diesel generator plants.

The Electrical Equipment of Pumping Stations

In the majority of the pumping stations of the trunk oil pipelines of Western and Northwestern Siberia, four centrifugal pumps driven by synchronous or asynchronous electric motors of either a standard or special design with an open ventilation cycle are installed: three working pumps and one standby.

The pumps and electric motors are located in rooms separated by a hermetically sealing wall, and are coupled together by intermediate shafts.

The production piping tying the main pumps together provide for the series connection of the pumps through a common collector with isolating check valves, which make it possible to start and stop any pumps without shutting down the other ones. The collector with the check valves and the electrically driven gate valves are located outside the pumping station building. A special site is provided for technical servicing of the gate valves, which is constructed alongside the collector at a height of two meters. The check valves are installed in the sump wells. The gate valves are driven by DNKh-714A motors with a power of 10 KW.

All of the pumping stations operate in a semiautomatic mode with remote control.

Summary data on the electrical equipment of oil pumping stations are given in Table 8.

The automation of a pumping station provides for operation without permanent attenting personnel. All of the major and auxiliary processes are controlled in a centralized manner from an operator's room located in the pumping station building. The automation system provides for the following:

--Automatic starting of the auxiliary mechanisms to prepare for turning the pumps on when the gate valve is opened at the suction intake station;

--Remote automatically programmed actuation of each main pumping unit;

--Automatic regulation of the maximum injection pressure of the station as well as the minimal suction pressure of the main pumps;

--Monitoring of the cooling conditions of the motors of the pump units;

--Automatic control of the convective exhaust ventilation with limiting of the oil vapor content in the air of the pump room at a level of no more than 20 percent of the lower limit of explosability and with the maintenance of the temperature in the pumping room in the range necessary for normal operation of the equipment and apparatus;

--Automatic control of the submersible pumps and the pumps for pumping out leaks depending on the level in the collecting reservoirs;

--Automatic disconnection of each of the operating units in case the normal operational mode of any of its assemblies is disrupted;

--Automatically turning on the back-up unit for any auxiliary system when the main ones fails;

TABLE 8.

Oil Pipelines and Pumping Stations	Main Pumping Station: Pump	Main Pumping Station: Electric Motor	Main Pumping Station: Power KW	Main Pumping Station: Voltage KV	Main Pumping Station: Speed r.p.m.	Support Pressure Pumping Station: Pump	Support Pressure Pumping Station: Electric Motor	Support Pressure Pumping Station: Power KW	Support Pressure Pumping Station: Voltage KV	Support Pressure Pumping Station: Speed r.p.m.
Ust'-Balyk--Omsk:										
"Karkateyevo" (head)	NM-7000x210	STD-4000-2	4000	6	3000	NMP-3600x78	DS-118/44-6	800	6	1000
"Vagay"	NM-7000x210	STDP-4000-2	4000	6	3000	NMP-3600x78	A12-46-6	800	6	950
All other oil pumping stations	NM-7000x210	STD-4000-2	4000	6	3000	NMP-3600x78	-	-	-	-
		ATD-5000-2	5000	6	2900	-	-	-	-	-
Nizhnevartovsk--Ust'-Balyk:										
"Nizhnevartovskaya I"	8MS7x10	A-13-46-4A	800	6	1445	-	-	-	-	-
	8MS7x9	VAO-630	630	6	1445	-	-	-	-	-
"Ur'yevskaya"	8MS7x8	VAO-800	800	6	1445	-	-	-	-	-
"Ur'yevskaya"	16ND-10x1	ARP-2000	2000	6	2900	-	-	-	-	-
	-	AZP-1600	1600	6	2900	-	-	-	-	-
"Surgut" (head)	16ND10x1	ARP-2000	2000	6	2900	20NDSN	AP-12-52-8A	320	6	745
"Ostrov" (head)	16ND10x1	AZP-1600	1600	6	2900	20NDSN	AP-12-52-8A	320	6	745
Shaim--Tyumen':										
"Shaim" (head)	14N12x2	AZP-1600	1600	6	2900	14NDSN	MAZ6-61/6	160	0.4	958
"Kuma"	14N12x2	ARP-1600	1600	6	2900	-	-	-	-	-
"Tyumen'" (oil filler)	14NDSN	MAZ6-61/6	160	0.4	958	-	-	-	-	-
Ust'-Balyk--Nizhnevartovsk:										
"Nizhnevartovskaya-II"	NM-700x210	STD-5000-2	5000	6	3000	NMP-3600x78	DS-118/44-6	800	6	1000
"Zapadnyy Surgut II"	-	ATD-5000-2	5000	6	2900	-	-	-	-	-
"Ur'yevskaya II"	NM-7000x210	STD-5000-2	5000	6	3000	-	-	-	-	-
Ust'-Balyk--Kurgan--Ufa--Al'met'yevsk:										
"Karkateyevo II"	NM-10000x210	STD-6300-2	6300	6	3000	NMP-5000x90	SDN-2/6	1600	6	1000
"Tyumen'"("Torgili")	NM-10000x210	STD-6300-2	6300	10	3000	NMP-5000x90	SDN-15-49	1600	10	1000
"Uvat II"	NM-10000x210	STD-6300-2	6300	10	3000	-	-	-	-	-
"Isetskoye"	NM-10000x210	STD-8000-2	8000	10	3000	-	-	-	-	-
"Setovo"	NM-10000x210	STD-8000-2	8000	10	3000	-	-	-	-	-
"Mugen II"	NM-10000x210	STD-8000-2	8000	10	3000	-	-	-	-	-
"Yuzhnyy Balyk II"	-	STD-6300-2	6300	-	-	-	-	-	-	-
	NM-10000x210	STD-6300-2	6300	10	3000			-	-	-

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--Automatic disconnection of one of the operating pumping units in case the injection pressure is excessively great either ahead of or following the control device, as well as when the intake pressure of the main pumps is excessively low;

--Automatic cutoff of all units and the disconnection of the station from the trunk line in the case of an alarm level increase in the injection pressure or a reduction in the intake suction pressure of the main pumps, as well as in the case when an elevated concentration of oil vapors is maintained for a long time in the air of the pumping room and in the event of the maximum alarm level in the reservoir collectors;

--Remote automatically programmed actuation of each of the pumping units and remote disconnection of the pumping station from the trunk oil pipeline with the simultaneous disconnection of the auxiliary mechanisms;

--Centralized monitoring of the major operational parameters of the pumping station, their recording and the requisite actuating and emergency signaling. A provision is also made for the control of each motor by means of pushbutton installed directly on the equipment. The automation hardware makes it possible to monitor the operation of the units both from the operator's position where all of the control equipment is installed as well as from the pumping station room.

The Electrical Power Supply for Pumping Stations

Deep entrance 110 and 220 KV substations with a secondary voltage of 6 or 10 KV are built to supply electrical power to oil pumping stations.

The step-down substations are dead-end types, designed primarily for powering the given pumping station and being operated by the personnel of the oil trans-pumping station, or are regional substations, designed to power not only one pumping station, but also other consumers. In this case, after the completion of construction, the substation is transferred to power system operation.

Regional substations are usually built for head-end pumping stations. The loads of head-end pumping stations are powered from regional substations, at which 500/110/10 KV or 220/110/10 KV autotransformers are installed, where the supply configuration additionally uses 10/10 KV regulating transformers with a capacity of 40 MVA installed on the 10 KV side.

Head-end oil pumping stations for trunk oil pipelines with a diameter of more than 1,020 mm, are included among first category consumers in terms of electrical power supply reliability; a dual independent supply configuration is provided for them. The intermediate stations on these oil pipelines likewise have a dual power supply.

A bridge circuit configuration with oil switches is used on the 110 KV side for first category consumers in the regions of Western Siberia. The power for oil pumping stations is supplied from 6(10) KV cubicle switchgear, which in turn receives electrical power from the 6(10) KV cubicle switchgear of 220 or 110 KV deep entrance substations via cable lines or open wires.

The cables are run in the open in standard production and special trestle supports. Running open wire conductors is more efficient. They posses a higher reliability than does cable. The current carrying conductors are made of type A-600 aluminum conductors. The flexible current conductor is strung on dual and single circuit standardized 110 KV supports.

The power transmission line is protected against direct lightning strikes by a type S-50 cable strung over the entire length of the current conductor.

A set of tubular RT-6 (10) dischargers is installed on the terminal support poles for the current conductor; KRU [complete switchgear] cubicles with VMP-10 oil switches having a PE-11 direct current drive are used in the 6 (10) KV oil pumping stations for the main motors; this switchgear is more reliable in operation than other types of cubicles in the case of frequent operational connection and disconnections.

The design values of the short currents are being increased because of the growth in the capacity of the Surgutskaya GRES, the changeover of the Tyumen'-Surgut power transmission line to a voltage of 500 KV and the two circuits of the Surgut-Megion power transmission line to a voltage of 220 KV, as well as because of the increase in the power of the electric motors of oil pumping stations.

Reactors are inserted to reduce the parameters of the electrical equipment and the cross-sections of conductors, as well as to limit the short circuit current.

CHAPTER SIX. THE ELECTRICAL POWER SUPPLY FOR OIL FIELD FACILITIES

Drilling Rigs

The drilling rigs in oil fields are powered from regional 110 KV substations and from deep entrance 35 KV substations, which belong to specialized organizations of the Main Tyumen' oil and gas administration. In new oil fields and in all gas fields, electrically powered powered drilling is powered from independent electrical power sources: from gas turbine PAES-1600-T/6.3 and PAES-2500-T/6.3 electric power stations.

Open wire 6 KV power transmission lines are constructed to transmit the electrical power to the drilling rig. The 10 KV voltage is not used. The open wire power transmission lines are constructed so that they can be subsequently used for providing electrical power to the field operating loads. Used as the supports for the open wire electrical transmission lines are SNVS-3.2 steel reinforced concrete poles and the spent drilling pipes with a diameter of 168 mm. Metal piles made of 219 mm in diameter pipes are used as the foundations for the support poles. When drilling prospecting wells, temporary open wire power transmission lines are constructed using wooden support poles, which are taken down following the drilling.

Open wire 6 KV lines on stock metal poles, secured to sleds are used on the taps off to bore holes (tap lines of up to 100 to 200 m).

Cable lines made of KShVG-6 and APVB-6 cables have found wide applications in drilling, where these cables are run in the open in difficulty accessible regions (swamps).

The electrical loads in 6 KV networks are determined by the number of drilling rigs operating simultaneously. The design electrical load can be determined by working from the simultaneous sumber of operating drilling machines for a given connection.

Number of Drilling Rigs	Design Load, KW
1	1,000
2	1,600
3	2,100
4	2,400
5 and more	3,000

The maximum length of a 6 KV power line is basically determined from the conditions for the sensitivity of the relay protection, and when drilling with one drilling rig, it runs up to 20 km from the substation. Starting in 1976, drilling rigs have been powered from 31 substations. The average design load for drilling in Western Siberia amounted to 40 MW in 1976, of which 15 MW went to the Samotlor field.

The electrical loads of a drilling are the drive motors of the the main and auxiliary mechanisms, as well as electrical lighting. The electrical power, within the confines of the borehole operation is distributed by 6 KV switchgear with power transformers for internal power requirements having a capacity of 160 to 250 KVA using open wire and cable lines rated at 6 KV, 500 and 380/220 V.

Depending on the type of drive for the draw works, two types of 6 KV switchgear are used:

KRNB-6 switchgear, consisting of six KRNB-6M cells and a TM-160/6 or TM-250/6 transformer, installed on a common transportable base; yet another cell is added to the distribution switchgear in the case where three drilling pumps are installed.

Switchgear based on YaKNO-6 cells, with a transformer for internal power requirements having a capacity of 160 or 250 KVA, and in the case where 500 volt motors are used in the draw works drive, two 6/0.525 KV transformers are used having a capacity of 600 KVA each.

The 500 volt network operates with an insulated transformer neutral and the 380/220 volt network operates with a grounded transformer neutral.

The meters for the accounting for the electrical power consumed by a drilling rig are located in the 6 KV supply substation cell, while the engineering metering is accomplished in the 6 KV cell at the drilling rig substation.

The average norm for electrical power consumption per meter of drilling is 40 KWH according to the Main Tyumen' Oil and Gas Administration. When drilling wells up to 2,400 m deep, the electrical power consumption per well fluctuates from 80,000 to 120,000 KWH, depending on the drilling operation conditions.

Oil Extraction Installations

Since the beginning of exploitation of the oil deposits of Western Siberia, a system of electrical power supply has been adopted for the operational wells (submersible pumps and sucker rod and deep pump installations) using individual 6/0.4 KV transformer substations for each individual well or for multiple wells. These substations are powered via single circuit open wire 6 KV lines.

In new fields, which were brought on line after 1974, the number of power supply centers for the electrical networks of the oil fields has been reduced. This is related to the use of combined sites for the various oil field structures and to the consolidation of the group pumping stations. The distances between 110 (35)

KV supply substations have been increased. While the distance between substations in "old" fields was about 3.5 km, it amounts to 10 km in the Fedorovskiy field and 8 km in the Agansk. The capacities of substations for groups of wells have been increased from 100-160 up to 400-630 KVA. Under these conditions, it is economically expedient to use 10 KV for the power to oil field electrical networks, something which makes it possible to reduce the number and overall length of power transmission lines.

A technical and economic comparison of the 6 and 10 KV network variants was made in the design of the operating equipment of the Agansk field; however, the data given here are for a conventional field with a length along the axis of 16 km, on which two 110 '35) KV substations are installed for the group pumping stations.

Submersible motors with a power of 55 KW arranged in groups of four to five wells each are used for well operation. The pumping station for external pumping of the oil is powered from a 10/6 KV substation with a capacity of 2x1.6 MVA.

Technical and Economic Data on 6 and 10 KV Power Transmission Lines

	6 KV	10 KV
Carying capacity of a line based on the economical current density, MVA	1.4	2.4
Cross-section of the wire, mm^2	120	120
Length of the line based on the permissible voltage drop, km	7	11.4
Number of lines	16	12
Length of the lines, km	103	96
Capital investments per transmission line, thousands of rubles	1,440	1,340
Number of 10.6 KV substations	-	1
Capital investments per substation, thousands of rubles	-	39
Overall capital expenditures, thousands of rubles	1,440	1,370
Amortization costs, thousands of rubles	44.6	43.6
Cost of electrical power losses, thousands of rubles	19	10.5
Overal operational costs	63.6	54.3
Referenced gas expenditures, thousands of rubles	279.6	261.2
The same, in relative units	1.7	1

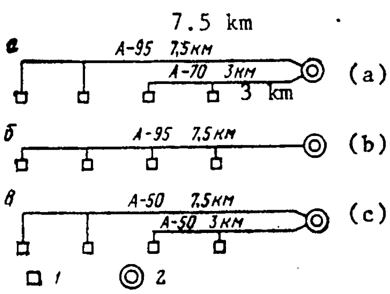

Figure 26. Electrical power supply configurations for groups of operating wells.

Key: a. Using a 6 KV power transmission line;
b,c. Using a 10 KV power transmission line;
1. Group of operating wells;
2. 35/6 (10) KV substation.

At the present time, the 10 KV voltage is used to power the oil field networks in the Agansk and Kholmogorsk fields, although the technical and economic expediency of this is obvious for a number of other fields (Severo-Tokursk, Fedorovskoye, etc.).

The 6 KV voltage is used for all other fields in service. This is due to the fact that the electric motors of the drilling rigs and pumping stations for trans-pumping the oil cannot be directly connected to the 10 KV networks and require addtional 10/6 KV transformation. Moreover, the temporary electrical power supply sources have a voltage of 6 KV, and a developed 6 KV networks is already on hand when the substations are introduced at the fields; it is difficult to change this network over to the 10 KV voltage.

We shall consider the electrical power supply for four groups of 36 operational wells with submersible 55 KW electric motors. The annual oil extraction is taken as equal to 1.5 millions tons. The installed capacity is 1,980 KW, the design load is 2,000 KVA and $\cos\phi = 0.75$.

To simplify the calculations, we assume that all of the wells are equipped with submersible pumps and the fact that the wells are not placed in service at the same time by mechanized means is not taken into account.

The conventional price for oil is adopted, which amounts to 95 percent of the output price for the Main Tyumen' Oil and Gas Administration (10.5 rubles/ton).

A technical and economic comparison of the different electrical supply variants (Figure 27) [sic] demonstrated that without taking into account the losses, the most economic variant is the second one with one 10 KV power line (Figure 27b) [sic], while the difference in the refernced expenditures between the first and second variants (Figures 27a and 27b) amounts to 45 percent. However, if the losses due to electrical power supply interruption are considered, the second and third variants (Figures 27 b and 27c) [sic] become of equal value.

Because of the lack of a uniform procedure for determining the losses due to power supply interruptions as well as reliable statistical data on the anticipated time of emergency disconnections, the calculations cited here should be considered as approximate ones. The losses due to reduction of oil extraction as a consequence of emergency disconnection of a power transmission line are of great importance, since they lead to completely different design solutions for the construction of the oil field network. In more precise calculations, the lack of simultaneity in changing the wells over to mechanized extraction must be taken into account. In the examples cited here, the variant in Figure 27c [sic] will prove to be even more economical in view of the fact that the construction of the second power transmission line can be extended over a longer term. The optimal timeframe for placing the second power transmission line in service depends on the timeframes for the shifting of the wells over to mechanized oil extraction.

The project planning for the operation of the Samotlor field by mechanized means was begun in 1974-1975; varaints of oil extraction by the gas lift method and submersible electric pumps were analyzed. In this case, the fact that submersible pumps of the requisite delivery are not series produced was taken into account. In the following, only the system variant for power supply to the groups of operating wells using mechanized extraction with submersible electric pumps with powers of from 55 up to 400 KW is treated.

It was assumed in the design calculations for an electrical power supply system under maximal loads that all of the wells are equipped with submersible pumps. In this case, the design loads for one group amount from 0.4 to 4.5 MVA; the average power transmission line length between the groups is 1.9 km. The average spacing between 110/35/6 KV substations, which are the power centers for the oil field power grid at a voltage of 6 and 35 KV, amounts to 6.5 km.

A technical and economic comparison of the electrical power supply variants, taking into account the requisite level of reliability, demonstrated that for an oil field distribution network in the central portion of a deposit, it is most efficient to utilize a voltage of 35 KV. The existing and planned junction substations for a 220 and 110 KV power system, which are located on the sites of the group pumping stations and KSP [not further defined], have the lower 6 KV voltage. The use of the 6 KV voltage was due to the necessity of rapidly placing the drilling rigs and electric motors of the pumping stations in service. And for this reason, the use of the 10 KV voltage for the power supply to groups was eliminated. The 6 KV voltage will be used to provide electrical power to groups of wells with loads of 0.4 to 0.6 MVA, which are located on the outskirts of the deposite, as well as for groups in the central region with loads of up to 1.4 MVA, which are located within a radius of up to 1 km from the 110 and 35 KV substations.

It is proposed that UKRUPN-6KhL1 distribution switchgear be used for the groups of the central portion of a field, powered from a 6 KV power transmission line. No less than two 6 KV lines per group are needed to power groups with loads of more than 1.4 MVA because of the limited carrying capacity of the 6 KV power transmission lines.

The loads of groups of injection wells, metering installations, electrical lighting and mechanisms for reparing the wells are connected to the 6 KV field networks. To power these loads, it is provided that a complete 6/0.4 KV transformer substation with a capacity of 40 to 100 KVA be installed at each group of injection wells. In the authorized electrical power supply variant for the groups of wells of the central portion of the Samotlor field, a ring network from single circuit open wire 35 KV lines was adopted with the installation of a 35/6 KV substation at each group. On the whole, it is proposed that 660 km of 35 KV lines (figured on a single circuit basis) be constructed with 256 substations at 35/6 KV as well as 680 km of 6 KV lines with 6/0.4 KV substations. The construction of the 35 KV power transmission line from the substations in accordance with the authorized scheme has been started.

The circuit and structural execution of the 35 KV network takes into account the necessity of providing for the highest power supply reliability to groups of wells, since in case one group is disconnected in the central region of a field, the oil extraction losses can amount to up to 8,000 tons/day. The following steps have been taken to improve reliability:

--Power supply to the 35 KV ring network from two sides from different 110/35/6 KV substations;

--The use of standardized metal power transmission line supports with suspension insulators and a lightning protection cable over the entire length of the line;

--The organization of reliable communications and signalling between the 35/6 KV substations and the power control bases.

From four to ten 35 KV substations are connected to each single circuit line which is powered from two sides. One of the switches is normally cut off, and in this case, some of the substations are powered from a single regional 110/35 KV substation, while the remainder of the substations are powered from a second regional substation. In an emergency, i.e., with a loss of voltage on the 35 KV buses of one of the regional substations, all of the 35 KV substations automatically switch over to power from the other.

At the present time, type KTPB 35/6 KV substations are used for installations at groups of wells, and in the future, type SKTPPN substations will be used. The type SKTPPN substations will have open 35 KV switchgear consisting of KhL design KTPB blocks and 6 KV type UKRUPN-6KhL1 switchgear. The capacity of the substations runs from 1x1.6 up to 2x4 MVA and the transformers have voltage regulation under load. The relay protection, communications and remote control equipment is housed in heated blocks.

Group Pumping Stations

The electrical power supply for group pumping stations, which depends on the production configurations for the development of the fields and the geographical conditions, can be broken down into three main groups:

--From the 35 KV network for group pumping stations of low output with a pumping volume of up to 720 m^3/hr;

--From the 110 KV network for group pumping stations with a pumping volume of up to 3,000 m^3/hr;

--From the 35 and 110 KV networks for group pumping stations which are not independent facilities, but are combined with other oil field installations.

Group pumping stations with three to four TsNS-180-1422 pumps and 1,250 KW motors, which are uniformly distributed over the territory of the field, and are not combined with other facilities, comprise the first group. Some 18 such group pumping stations are located in the Mamontovskoye field. A 35/6 KV substations is constructed at each of them, which is simultaneously the power center for the 6 KV oil field network. The 35 KV network is made in the form of dual circuit lines, which are powered from the 110/35/6 KV "Mamontovskaya I" and "Mamontovskaya II" substations (Figures 27 and 28).

In terms of electrical power supply reliability, group pumping stations belong to the second category. It is quite important to provide uninterrupted electrical power to the 0.4 KV group pumping station consumers, especially the emergency electrical heating for the pumping units, the electrical heating of the water lines, the electrical heating for the shelter of the artesian pumps as well as power for the communications and remote control equipment. A long term power outage in the supply for the electrical heating in the case of nonoperating pumps can lead to freezing and the failure of the pumps and water lines.

The requisite power supply reliability for group pumping stations is achieved by using dual transformer 35/6 KV substations and dual transformer 6/0.4 KV substations powered from different sections of the 6 KV buses and an automatic reserve switching device on the 6 and 0.4 KV side.

The 35/6 KV KTPB (complete transformer substation packages in a modular design) substations are widely used to provide electrical power to group pumping stations. The KTPB substations consist of blocks which are completely finished at the factory, and the volume of construction and installation work on the site is minimal. Complete rigid buswork for the 35 KV blocks as well as cable trays are also supplied by the plant.

However, the present KTPB design does not meet the operational requirements for Western Siberian conditions, since it is designed for use at a temperature of no lower than -40 °C, while the 6 KV switchgear consists of K-37 cells for outdoor installation, which do not have any heating and are inadequately reliable at low temperatures.

A KTPB structural design in a KhL design is being developed at the present time with heated 6 KV switchgear; it is also planned that the type K-37 6 KV switchgear cells will be replaced by the improved and more reliable K-42 cells.

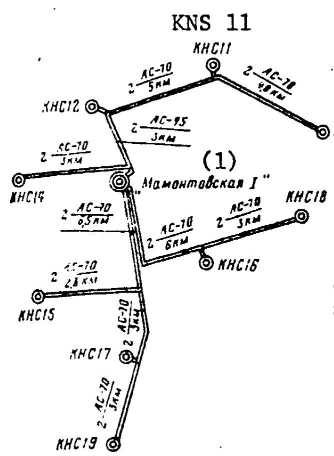

Figure 27. The electrical power supply configuration for a group pumping station from the "Mamontovskaya I" substation.

[KNS = group pumping station].

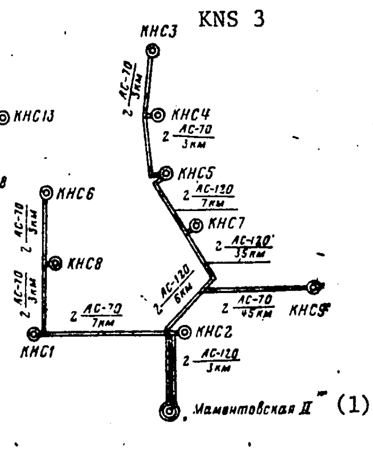

Figure 28. The electrical power supply configuration for a group pumping station from the "Mamontovskaya II" substation.

A drawback to the electrical power supply configuration for block group pumping stations from a KTPB substation (Figure 29a), which is being used at the present time, consists in the fact that the 6 KV switchgear of the substation and the 6 (10) KV switchgear of the BKNS duplicate one another. In this case, the substation and the BKNS are completely autonomous. This leads to redundant 6 (10) KV equipment, and also reduces the operational reliability of the entire installation, since four switches are inserted in series in the circuit of the pump electric motor. The large number of 6 (10) KV switches makes it difficult to align the selective operation of the relay protection, since the number of time delay stages in the maximum current protection is increased.

A more economical electric power supply configuration for the BKNS's, the introduction of which was started in 1975, is shown in Figure 29b. The Tyumen' plant for modular devices has begun the manufacture of BKNS 6 (10) KV switchgear for this circuit configuration, with the addition of four cells to provide power to the oil field grid, something which has made it possible to dispense with the sectional 6 (10) KV switch at the 35/6 KV substation.

The most reliable economical circuit configuration is one in which 6 (10) KV switchgear of the substation and the BKNS are completely combined (Figure 29c). The electrical power is supplied to group pumping station 15 of the Samotlor

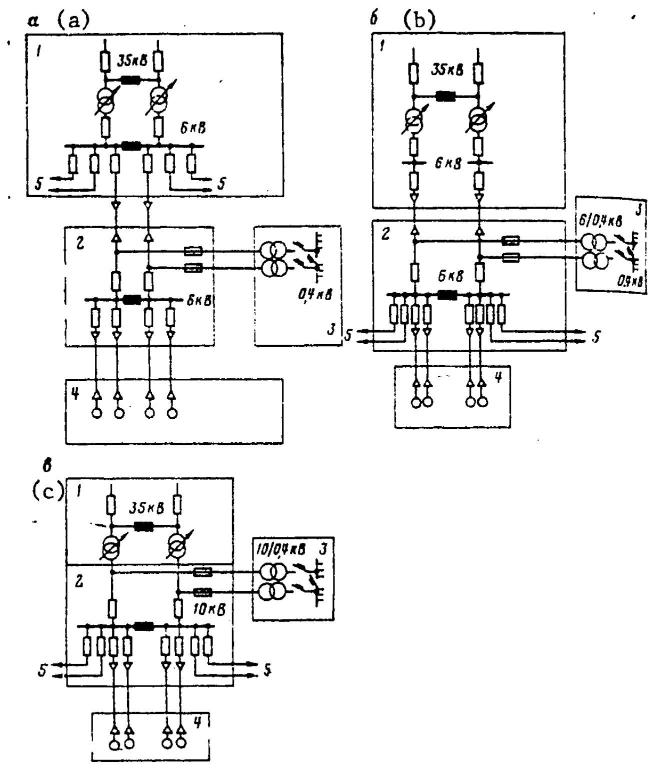

Figure 29. Electrical power supply circuits for BKNS's [modular group pumping stations] with TsNS-180-1422 pumps.

Key: a. First variant;
b. Second variant;
c. Third variant;
1. 35/6 (10) KV substation;
2. 6 (10) KV switchgear block;
3. Control block;
4. Pump block with type STD-1250-2 electric motors, 1,250 KW, 6 (10) KV;
5. Power supply lines for the oil field loads.

field and certain others using the principle of combining the 6 (10) KV switchgear of the substation and the BKNS. A comparison of the variants based on the number of equipment units is given in Table 9.

In the third variant, not only is a savings of a considerable quantity of equipment achieved, but the outlays for the construction of the BKNS are reduced because of the decrease in the overall construction site area, the length of the roads and the amount of foundation material under the equipment.

A plan view of a modular group pumping station with a type KTPB 35/6 KV substation in accordance with variants 1 and 3 (Figure 29a and 29c) is shown schematically in Figure 30; it can be seen from this that the overall area occupied by the electrical power supply structure third variant is reduced by 22 percent. However, simultaneous delivery of the equipment is not assured, since the block of the substation and 6 (10) KV switchgear of the BKNS [modular group pumping station package] are manufactured by different interprises. It is impossible to bring the 35/6 KV substaion on line without the 6 KV switchgear of the BKNS. Placing the 35/6 KV substation in service, regardless of the timeframes for the construction of the BKNS, is necessary to provide electrical power to the priority loads of the field, primarily, the drilling rigs. Moreover, there is no control panel in the KTPB substations, while all of the relay equipment is located in the 6 KV switchgear cells. Since the 6 KV switchgear is not supplied by the manufacturing plant of the KTPB in the third variant, the control panel must be ordered separately.

TABLE 9

Equipment	Number of Equipment Units According to the Following Variants		
	First	Second	Third
6 (10) KV entrance cells	4	4	2
Cells of Sectional switches	4	2	2
Cells of bus voltage transformers	4	4	2
Cells of internal power requirement transformers	6	6	2
Cells of outgoing lines	6	6	4
Cells for the electric motors	8	8	4
Internal power requirement transformers	4	4	2
Control station panel	-	-	1
Control panel	-	-	1

The volume of water pumped by each group pumping station is quite large in large fields with high output wells and a limited number of group pumping stations. Group pumping stations with four to five TsNS-500-1900 pumps and electric motors with a power of 4,000 KW are used under these conditions. The overall load in this case amounts to 15 to 20 MW, and taking into account the loads of the field network (the operating wells), it is 20 to 50 MW. With such loads, the use of

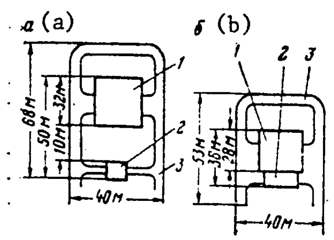

Figure 30. Plan view of a BKNS [modular block group pumping station].

Key: a. First variant;
b. Third variant;
1. 35/6 (10) KV KTPB [complete modular transformer substation package];
2. 6 (10) KV switchgear of the BKNS;
3. Roads.

35 KV network for the electric power supply of group pumping stations is not expedient and a voltage of 110 KV is used. A schematic of the power supply for KNS 15 [group pumping station] of the Samotlor field is shown in Figure 31; four TsNS-500-1900 pumps are installed in this station and deliver 3,000 m^3/hr.

The 110/35/6 KV substation of KNS 15 with a capacity of 2 x 40 MVA of the KTPB type (Figure 31a), designed in a simplified circuit configuration, is in constant operation for the enterprises of the power system. The entire capacity on the 6 KV side is transmitted directly from the transformers to the switchgear of the group pumping station, which is operated by the Nizhnevartovsk Power and Petroleum Administration of the Main Tyumen' Oil and Gas Administration.

The group pumping station switchgear has open wire entrances and is connected to the transformer by two current conductors. Flexible current conductors made of 2ASO-600 wire with a length of 40 meters per phase are strung on portals with a height of 7.5 m. The permissible load for each conductor is 2,000 amps.

The switchgear of the group pumping station has four sections of 6 KV buses (see Figure 31b). The third and fourth bus sections are powered from the first and second sections respectively through reactors. Some four synchronous STD-4000-2 motors are connected to the third and fourth bus sections, while all remaining consumers are connected to the first and second sections.

The equipment for the 6 KV switchgear of the NKS [possible typo for KNS] is chosen by working from the conditions for its stability in the case of short circuit currents. The shock short circuit current on the 6 KV side of the 110/35/6 KV substation is composed of the currents from the power system (50.5 KA) and the make-up current from the synchronous motors (16.5 KA), and is equal to 67 KA, which exceeds the dynamic stability of the electrical equipment of the usually employed K-XII and K-37 cells. Because of this, K-X and K-XXI type switchgear cells with VEM-6 switches are used for the 6 KV switchgear; the dynamic stability of the electrical power equipment of the cells is 100 KA.

There is almost no 6 KV switchgear at all at the 110 KV substation; only the cabinets with the voltage transformers and the transformers for internal power requirements have been retained. The elimination of 6 KV switchgear at the substation, besides the obvious savings in equipment and the reduction of construction and installation work, is also due to the fact that the plant can supply the KTPB's only with the K-37 and K-33 cells, the dynamic stability of the electrical equipment of which is 52 KA. In the adopted circuit configuration, there are no unstable switches in the 6 KV circuit. The only sections which remain unstable to the action of short circuit currents are the buses of the four K-37 cells and the cells with the internal power requirement transformers.

Because of the lack of 6 KV switches at the substation, the entrance switches of the 6 KV switchgear of the group pumping stations are used to protect the 110/35/6 KV transformers. In this case, the 6 KV current conductors are also included in the transformer protection coverage area. The adopted configuration leads to the necessity of joint operation of a portion of the equipment of the 6 KV switchgear of group pumping stations by enterprises of the power system and the Main Tyumen' Oil and Gas Administration.

We shall analyze the electrical power supply for group pumping stations, which are combined with other oil field facilities, in light of the example of the group pumping stations of the Yuzhno-Balyk field (Figure 32).

The group pumping station of the Yuzhno-Balyk field, with six TsNS-180-1422 pumps, is located on one site with the supplemental transpumping station (DNS). The DNS serves for pumping the oil from the western portion of the field to the collection point and consists of four pumps with electric motors having a power of 160 KW each at 0.4 KV. The two BKNS's produced by the Tyumen' Repair and Mechanical Plant for the given facility are delivered without the 6 KV switchgear blocks and without the 6/0.4 KV transformers.

The integrated 6 KV switchgear (Figure 32a) serves to power all DNS, KNS and field network consumers at a voltage of 6 KV. The 6/0.4 KV type KTP [complete transformer substation package] substation for powering the internal loads of the 6 KV switchgear and all of the 0.4 KV loads of the group pumping stations is housed in the building for the 6 KV switchgear. The separately sited 6/0.4 KV substation for a supplemental transpumping station is powered from the integrated 6 KV switchgear. The 6 KV integrated switchgear, which is designed in accordance with an individual project plan in each individual case, has found widespread applications in all Western Siberian fields. The number and type of KRU [complete switchgear package] cells in the integrated switchgear can vary. They differ as well in terms of the kind of operating current and set of control panels. A schematic of the 0.4 KV network is shown in Figure 32b.

The K-XII KRU cells are used because of the force of the shock short-circuit current of up to 52 KA on the 6 KV buses; for a nominal current level of up to 1,500 A, K-XII cells are likewise used as the entrance and sectionalizing cells; complete switchgear package cells of the K-XV type are used for a nominal current level of up to 3,000 A; KRU-2 cells are used for the same dynamic stability and the same nominal current levels. In the case where K-XII, K-XV and KRU-2 switchgear cabinets are used as the operating current source, BPN and BPG units serve as the power supplies.

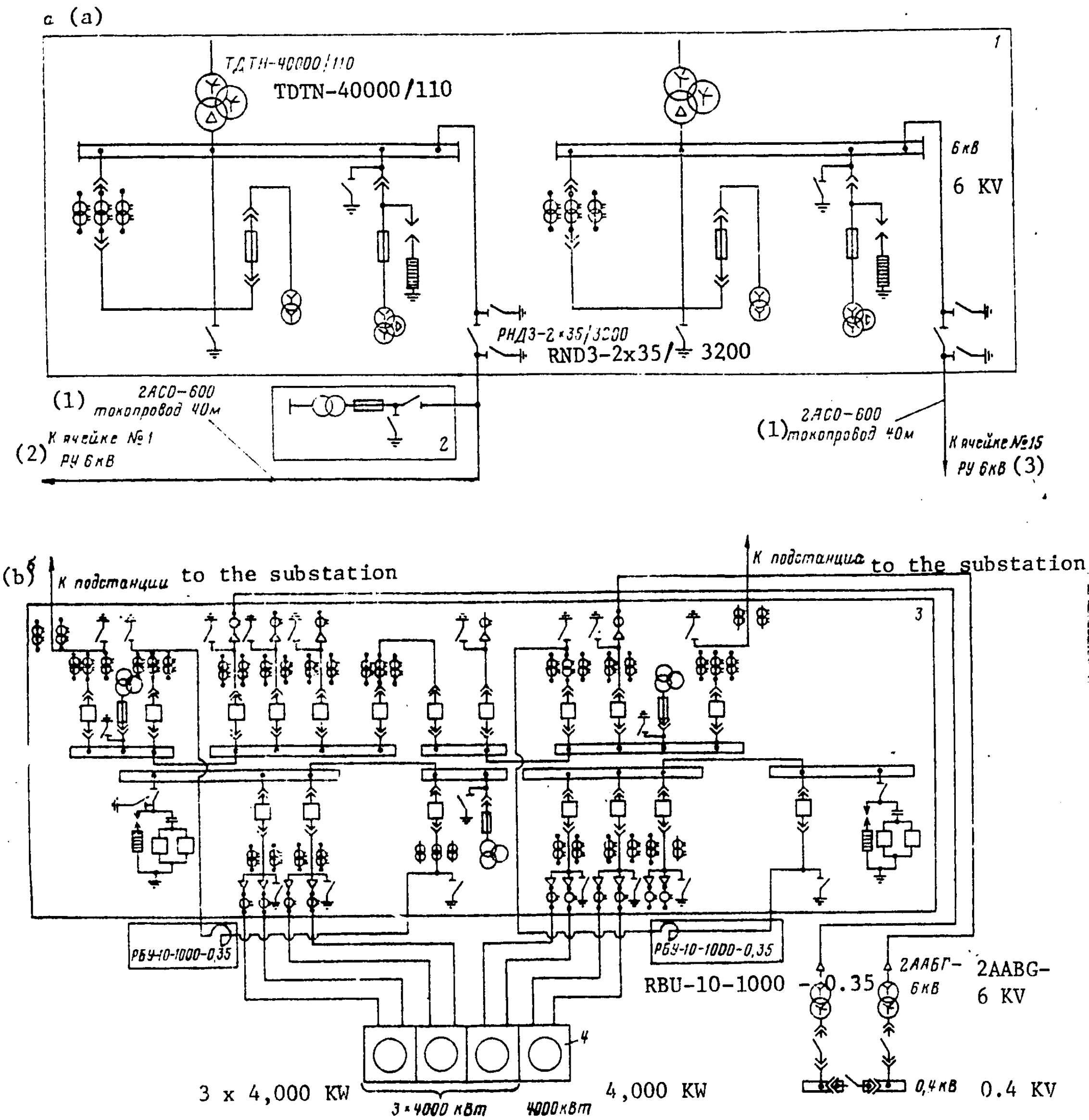

Figure 31. The electrical power supply circuit configuration for KNS 15 [group pumping station 15] of the Samotlor field.

Key:
- a. Substation circuit;
- b. 6 KV switchgear circuit;
- 1. Block of the KTPB substation;
- 2. Internal power requirement transformer block;
- 3. 6 KV switchgear;
- 4. Pump blocks;
- (1). 40 meters of 2ASO-600 current conductor;
- (2). To cell No. 1 of the 6 KV switchgear;
- (3) To cell No. 15 of the 6 KV switchgear.

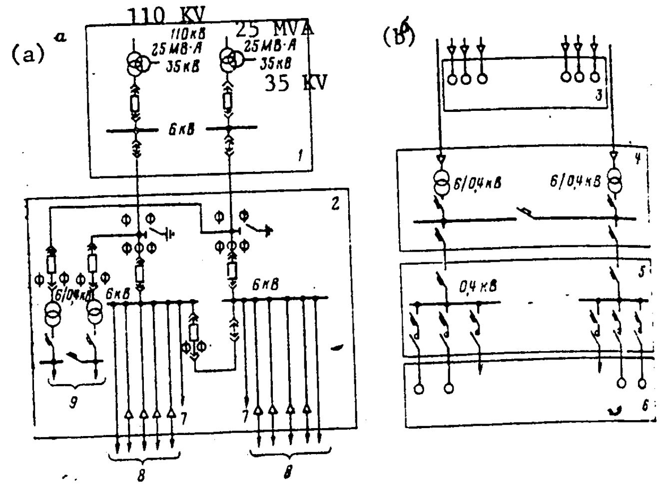

Figure 32. Electric power supply circuit configuration of the group pumping stations and supplemental transpumping station of the Yuzhno-Balyk field.

Key:
a. Circuit of the 110/35/6 KV substation and the [6] KV switchgear;
b. Circuit of the 0.4 KV network;
1. KTPB [complete modular transformer substation package];
2. Combined 6 KV switchgear;
3. Group pumping station with six STD-1250-2, 1,250 KW, 6 KV motors;
4. 6/0.4 KV complete transformer substation;
5. "Elektroshchit" DNS [supplemental transpumping station];
6. DNS consumers;
7. 6/0.4 KV complete transformer substation;
8. To the motors of the group pumping stations and to the multiple wells;
9. To the distribution switchgear internal load consumers.

For a short-circuit shock current level of from 52 to 100 KA, K-X, K-XXI or KR-10/500 cells are employed, and in this case, the entrance and sectionalizing K-XXI cells have a nominal current level of 2,000 A. A DC operating current, the source of which is the type ShUOT operating current control cabinets with a built-in storage battery at a voltage of 110 or 220 volts, or permanent storage batteries, is used for the K-X and K-XXI complete switchgear package cells.

The substations for the 110 KV power system, which power the integrated switchgear, have various circuit configurations, and the 6 KV switchgear is correspondingly made with different circuits for the secondary connections and different sets of control panels. The technical data for some of the integrated 6 KV switchgear are given in Table 10.

TABLE 10.

Kinds of Equipment and the Technical Specifications	Installation Site in the Fields		
	Samotlor KNS 15	Fedorovskoye KNS 2	Samotlor KNS 21
Types of entrance and sectional complete switchgear package cells	K-XXI	K-XV	K-XII
Nominal current of the entrance cells, A	2,000	3,000	1,500
Type of cells of the outgoing lines	K-X	K-XII	K-XII
Number of complete switchgear package cells for the synchronous motors of group pumping stations	5	4	4
Number of complete switchgear package cells for powering the asynchronous motors of supplemental transpumping stations	-	6	8
Number of other outgoing lines	2	9	10
Total number of complete switchgear package cells	23	45	42
Operating current source	Storage battery	Power supplies	Power supplies
Capacity of the built-in complete transformer substation, KVA	2 x 400	2 x 400	2 x 400
Number of blocks of the 6 KV switchgear building	12	11	11
Overall plan-view dimensions of the 6 KV switchgear, m	43.2 x 5.7	39.6 x 5.7	39.6 x 5.7

To retain the principle of the industrical method of constructing the buildings for integrated 6 KV switchgear for the entire range of types and numbers of units of the main electrical equipment, all such switchgear is assembled from individual sections with plan-view dimensions of 5.7 x 3.6 m. Each section consists of a metal frame, a base and heated metal enclosing structures. The 6 KV switchgear buildings are manufactured at the plant and delivered to the construction site in the form of individual sections.

The Oil Bearing Formation Pressure Maintenance Water Supply System

After switching the PPD [formation pressure maintenance] water supply system over to the trunk circuit, a water supply system is formed which consists of the pumping station water intake and all of the KNS's [group pumping stations] of one or more fields. In the case of interruptions of the electrical power to severals KNS's, the water supply system continues to function, only the electrical loads are reduced. However, if the electrical power supply to the pumping station water intake is disrupted, and consequently, the delivery of water to the group pumping stations is terminated, then there is a complete disconnection of the entire load of the PPD system by the protection against a drop in the injection pressure (at all KNS's). Interruptions in the electrical power supply can be of a short term nature, and in this case, the electrical power supply to the users is restored by the action of the APV [automatic reclosing circuitry] (a successful APV action comprises 50 to 60 percent of the overall disconnections).

However, all of the KNS motors and the pumping station water intake, following the restoration of the power, proved to be disconnected as a result of the actuation of the high speed protective circuitry. The automatic starting of the KNS motors with the pumping station water intake cut off is not effective, since with the lack of water pressure in the trunk water main, the KNS motors are again cut off. Thus, for a successful automatic reclosing in a power system it is important to turn on the pumping station water intakes without delay or to maintain their power when the electric power supply of the KNS's is disrupted.

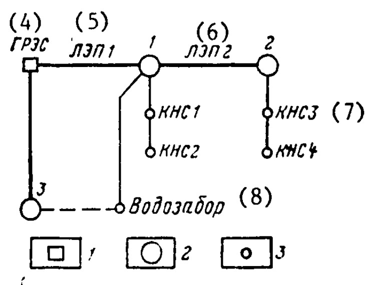

Figure 33. Schematic of the electrical power supply for a formation pressure maintenance system.

Key: 1. State regional electric power station;
2. 220 KV substations;
3. 110 KV substations at the group pumping stations and water intake;
4. GRES [state regional electric power station];
5. Power transmission line 1;
6. Power transmission line 2;
7. KNS 3 [group pumping station];
8. Water intake.

We shall analyze the possible emergency conditions in the electrical power supply circuit of a PPD system (Figure 33). With the disconnection of one of n group pumping stations, the PPD system remains in operation, however, the load is reduced by 100/n percent.

In the case where the 200 KV power transmission line 2 is disconnected between substations 1, the PPD system continues to operate. In the initial period (following successful automatic reclosure of the 220 KV line), the GRES load is reduced by 50 percent. Since the pumping station water intakes do not lose power (it is maintained from substation 1), then following the automatic reclosure on the 220 KV line, the motors of KNS 3 and KNS 4 are automatically started and the load is fully resotred.

In case the 220 KV power transmission line 1 is disconnected, the load is completely dumped. Following successful automatic reclosure, the pumping station water intakes should be turned on as fast as possible (autostarting of the motors) to restore the water pressure in the main water lines. Then the automatic start of the group pumping station motors provides for the restoration of normal operation of the entire water supply system. The greatest reliability is achieved in the case of autonomous power for the pumping station water intakes via two separate lines (it is shown in Figure 33 by the dashed line).

Synchronous motors, which do not require the quenching of the field during power outages and resynchronization, are the most convenient for autostarting. Calculations of autostarting conditions for the motors of the second stage water intake pumping stations at the Samotlor field show that when power is supplied from a 110/35/6 KV substation with a capacity of 2 x 40 MVA, in a minimum operational mode for the power system, it is possible to simultaneously autostart two motors with a power of 2,500 KW each (the second lift) and six motors with a power of 250 KW each (the first lift) from each section of the 6 KV buses. In this case, the voltage on the buses will amount to 79%, a figure which meets the norms. The remaining 12 motors in the case of power interruptions are disconnected by the fast-acting protective circuitry with subsequent automatic sequential starting with a time delay.

Those synchronous motors which operate with a current lead, and provide a specified power factor for the power system of 0.92 on the whole for each oil field, are used in the Western Siberian fields for group pumping stations. In this case, there is no need for special units to compensate for the reactive power.

Synchronous motors are more stable with respect to drops in the supply voltage and have a higher efficiency than asynchronous motors. However, after the construction of the PPD water supply system for one or several fields, it turned out that the use of just synchronous motors is not expedient, since synchronous motors with brushless excitation do not allow for resynchronization and rapid quenching of the field. The system adopted for automatically starting the motors after power is restored is inadequately effective, since the time delay for self-quenching of the motor field should be no less than five seconds. For this reason, it is expedient to have up to 20 - 30% of the motors in the form of asynchronous motors at group pumping stations, where these motors allow for self-starting. This increases the PPD water supply system reliability and reduces the possible load fluctuations in the power system. The possibility of using asynchronous motors in PPD water supply systems for the oil fields of Western Siberia is confirmed by design calculations of the electrical loads for the case where the fields are in full production.

When starting group pumping station motors with powers of 1,250 - 4,000 KW, the voltage on the 6 KV buses of the supply substation falls off for a short time. The starting of the motors is usually accomplished, even when the voltage drops to 55% of the nominal, since the load on the motors is a centrifugal pump. A short term voltage drop at the terminals of the remaining operating motors does not cause them to drop out of sync, something which is helped by effective boost excitation. For normal operation of all the remaining consumers connected to the same substation, it is necessary to provide a voltage of no less than 75% of the nominal in accordance with the existing standards. The residual voltage across the 6 (10) KV buses depends on the power system capacity, the lengths of the 35 (110) KV lines, the capacity of the 35 (110) KV transformers, as well as their loads. Calculations show that when starting 1,250 KW motors from 110 KV transformers with a capacity of 16 to 40 MVA, the remaining voltage amounts to no less than 75% of the nominal.

35 KV power line

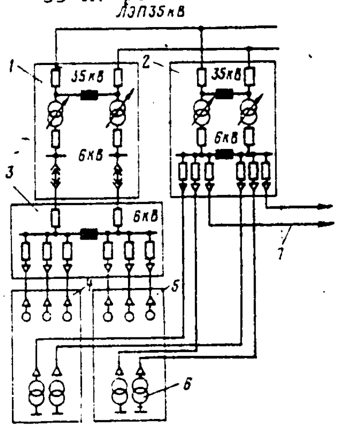

Figure 34. Schematic of the electrical power supply for group pumping station 5 of the Vatinsk field.

Key:
1. 35/6 KV substation No. 1 with a capacity of 2 x 6.3 MVA;
2. 35/6 KV substation No. 2 with a capacity of 2 x 2.5 MVA:
3. The integrated 6 KV switchgear;
4. BKNS [modular block group pumping station] No. 1 with three TsNS-18-1422 pumps;
5. BKNS No. 2 with three TsNS-180-1422 pumps;
6. 6/0.4 KV transformer with a capacity of 160 KVA;
7. Lines to provide power to the oil field grid.

When starting 4,000 KW motors from the same transformers, the remaining voltage is less than 75% of the nominal in all cases, and for this reason, it is necessary to use reactors to assure the requisite residual voltage level. When starting 1,250 KW motors from 35/6 KV transformers with capacities of 4 to 6.3 MVA, various residual voltage levels are obtained, depending on the specific conditions, in which case, the use of reactors does not yield the desired result in a number of cases. For this reason, if the residual voltage does not meet the norm when a group pumping stations is powered from a 35/6 KV substation, it is necessary to install two 35/6 KV substations on the group pumping station site. One of them serves only to provide power to the group pumping station motors, and no other consumers are connected to it. The second substation is intended for powering the groups of operating wells, provide electrical power for the supplemental transpumping stations and power the 6/0.4 KV transformers of group pumping stations. A schematic of the electrical power supply for group pumping station 5 of the Vatinsk field, designed on this principle, is shown in Figure 34.

Oil Pumping and Compressor Stations within a Field

The oil pumping stations in the oil fields of Western Siberia are usually not independent facilities, but are always combined with comprehensive collection points (KSP's), oil preparation installations, or with group pumping stations. The electric motors of the pumping units are powered via 6 KV cable lines from the integrated switchgear which also serves to power other consumers.

The power supply for an oil pumping station consisting of six blocks with electric motors having a capacity of 320 KW each is schematic of the electrical power supply for KSP 6 of the Samotlor field (Figure 35).

To increase the power supply reliability for a pumping station, its motors are connected to the first and second sections of the 6 KV switchgear buses, which have an automatic standby switching unit. These bus sections are isolated by reactors from the third and fourth sections of the supply buses for the high power group pumping

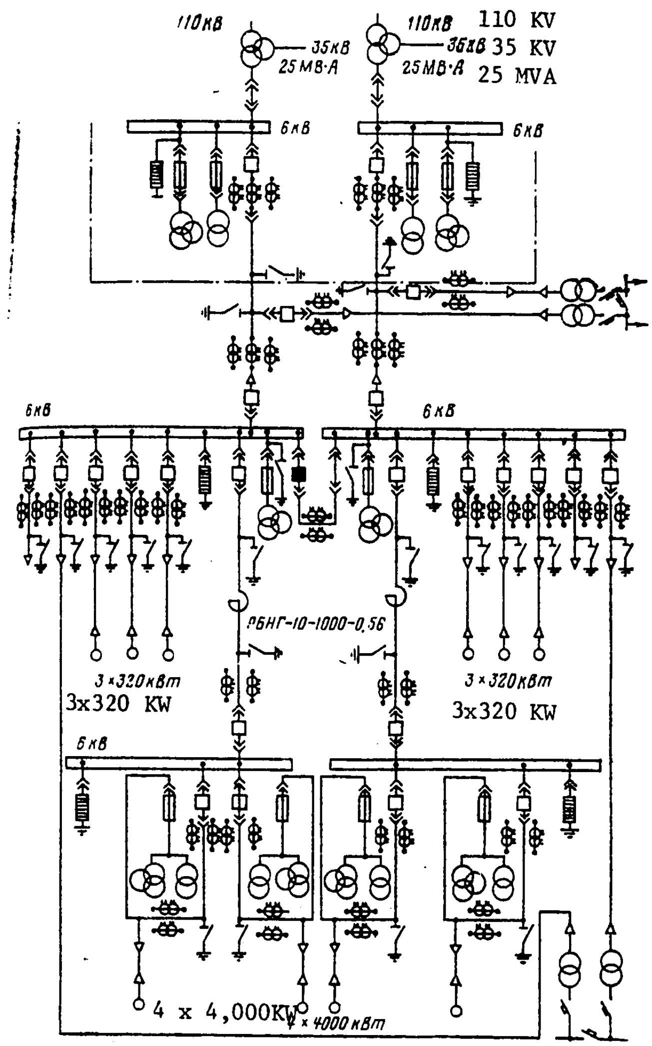

Figure 35. Schematic of the electrical power supply for KSP 6 [comprehensive collection point 6] of the Samotlor field.

station motors, something which assures a more stable supply voltage for the oil pumping station.

If 6 KV electric motors are used at an oil pumping station, then they are powered via cable lines from the integrated 6 KV switchgear. The other electrical power consumers of the oil pumping station are powered from a 6/0.4 KV transformer substation. The oil pumps with the 0.4 KV electric motors are connected to the same substation, the capacity of which is increased correspondingly.

Provisions are made for powering the auxiliary electrical equipment at a voltage of 380/220 volts at oil pumping stations from complete transformer substations at 6/0.4 KV with capacities of 2 x 250 to 2 x 400 KVA, by means of the distribution panels of the control stations. Since the pumping units are assigned to Class B-1a explosion hazardous rooms, the electrical equipment is installed in separate electrical equipment rooms. The electrical equipment rooms have light metal heated enclosing structures, similar to the structures for the pumping unit.

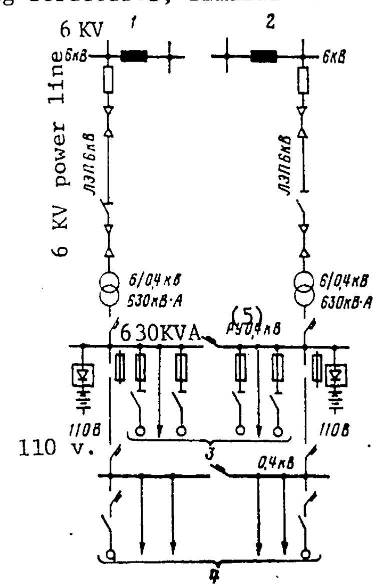

Figure 36. Schematic of the electrical power supply for compressor station "B" of the Pravdinsk field.

Key: 1. Buses of the 6 KV switchgear for group pumping station 2;
2. Buses of the 6 KV switchgear for group pumping station 3;
3. Motors for the production process equipment;
4. Motors for the auxiliary equipment;
5. 0.4 KV switchgear.

The signaling for the operation of the oil pumping plant is brought out on the KSP operator's panel, and transmitted via remote control channels to the dispatcher points.

Compressor stations are used in the Western Siberian fields to deliver byproduct gas to the wells in the case of mechanized, gas lift oil extraction.

In the Pravdinsk field, the gas lift extraction system is serviced by three compressor stations. Gas motor drives are used for all compressors and electrical drives are used for the auxiliary mechanisms. The 0.4 KV voltage distribution panels, station control panels and rectifier installations with the storage batteries are installed in a room built into the compressor station building. Two 6/0.4 KV transformers with capacities of 630 KVA each are housed in individual chambers. The electrical power is supplied to the compressor station from the 35/6 KV substations of group pumping stations 2 and 3 via single circuit open wire lines at a voltage of 6 KV. In terms of the level of electrical power supply reliability, compressor stations are assigned to the first category. The control circuits of the compressors, electric motors of the production process equipment, the 0.4 KV switchgear for the internal power requirements and other important secondary circuits are powered from two rectifier installations with 110 volt storage batteries. Provisions are made for the simultaneous self-starting of all the electric motors of the production process equipment without any time delay following short term interruptions in the electric power, as well as in the case of the action of the automatic standby switching and automatic reclosing devices. A schematic of the electrical power supply is shown in Figure 36.

The station for feeding byproduct gas from the Ust'-Balyk field to the Surgutskaya GRES belongs to a different type of compressor stations. The project plan for the station provides for the use of nine 10 GKN compressor plants with a gas motor drive having a power of 1,500 h.p. each. Electrical drives are used for the auxiliary mechanisms, with a design load of 400 KW. Electrical power is provided from the 6 KV network through 6/0.4 KV transformers. The electrical power consumers are assigned to the second category in terms of the level of reliability.

* * *

CHAPTER 7. INDEPENDENT ELECTRICAL POWER SOURCES AND POWER TRANSMISSION LINES

Independent Power Sources

Independent permanent or mobile electric power generators are usually employed for the electrical power supplied to oil and gas fields in the early stage of their development. G-65 and G-66 generator plants with a type 6-ChN-36-45 engine and the GSD-630-375, 400 (630) kilowatt generator at 6,300 volts and 300 r.p.m. are used as the electric power sources in permanent electric power stations. The diesel electric power plant and 6 KV switchgear are housed in frame and panel type rooms. The warehouses for the fuel, lubricants and the cooling towers are erected on the open site of the diesel power station.

The use of 6 KV generators has made it possible to distribute electrical power over a radius of up to 6 km without step-up transformers. The 6 KV networks were subsequently connected to the state power system.

Along with the use of fixed diesel electric power plants, mobile electric generators are widely used. The transportability, presence of a complete equipment set and modular construction make it possible to use them in remote difficulty accessible regions to provide power for small loads. The ESD domestic mobile electric power stations are widely used in the fields of western Siberia (the technical specifications are given in Table 11) as well as foriegn manufactured ones from the Polish Peoples Republic and the Czechoslovakian SSR with capacities of 100, 150 and 200 KW with three-phase 50 Hz AC generators.

Type AB plants with capacities of 4, 8 and 15 KW which run on gasoline have found wide applications in communications offices.

Diesel electric power stations have a limited engine service life, low unit capacities of the diesel generators, requre numerous service personnel and need fuel from the central regions.

Because of the rapid pace of development of the oil and gas extraction industry, the construction of group pumping stations for a system to maintain rock formation pressure with electric motors having capacities of up to 1,250 KW and oil pumping stations with electric motors having capacities of up 1,600 KW, it has become necessary to build larger independent electric power stations. In considering the variants of electrical power sources, the economic expediency of using all kinds of electric power stations operating on shipped-in fuel was demonstrated, since local fuel is available: oil or byproduct natural gas. The decision was made to use steam turbine power trains as temporary power supplies, which run on crude oil or byproduct natural gas.

A power train takes the form of a complete steam turbine condensation electric power station, mounted in railraod cars. Power trains were delivered to the installation site with specially equipped barges having a cargo capacity of 1,500 tons via rivers, while they were loaded and unloaded at special wharves. Because of the severe climatic conditions, the power trains were housed in special heated readily assembled and disassembled panel and frame structures.

During 1964-1965, 15 energy trains were sent to the northern regions of the Tyumenskaya oblast. Some five energy trains were assembled in Ura; five B-4000 energy trains in Nfteyugansk; two B-4000 energy trains in Surgut; three B-4000 energy trains in Nizhnevartovsk; and one B-4000 in the Strezhevoy settlement in the Tomskaya oblast.

The installation of power trains has engineering and economic advantages over the construction of temporary (before connection to the power system) diesel electric power stations of similar capacity: the timeframe for the execution of the work is significantly curtailed, as well as the requisite facilities for the creation of a stable electrical power supply; the time for the start-up and debugging work is also reduced; a more reliable electric power supply is provided to consumers as well as the capability of starting electric motors of a large unit capacity; the capital investments are significantly reduced, since the cost per kilowatt of installed capacity of a power train amounts to about 200 rubles, while for a temporary fixed diesel electric power station of the same capacity, it is 350 rubles.

The number of cars incorporated in a power train depends on the cooling system as well as the number of service cars, shop cars and dormitory cars. The power trains operating in the oil fields of western Siberia have from five to nine cars in their complement. One turbine car is included in the complement of all power trains, as well as two or three boiler cars, one distribution switchgear car, and one auxiliary equipment car. The bringing of power trains on line has made it possible to completely provide electrical power to a city and electrify oil and gas field facilities as well as drilling rigs.

The direct connection of electric motors to the 6 KV network, the capacity of which is commensurate with the capacity of the power train generators, has necessitated matching the characteristics of the automatic controllers for feeding steam to the turbine and the excitation of the electric generators operating in parallel with the power train. However, after the appearance of mobile gas turbine electric power stations, the installation of power trains was terminated.

Electric power stations with aviation gas turbine engines, as compared to steam turbine power trains, have lower specific capital investments, provide for rapid starting and assumption of the load, they have a higher degree of transportability and lower operational expenses. These electric power stations can be set up in any oil field where there is natural gas. Electric power stations with the AI-20 aviation gas turbine engine have proved to be the most promising.

Series production of the PAES-1600-T/6.3 mobile electric power station, which runs on byproduct natural gas, was started in the nation using this engine in 1968. Production was set up for the PAES-2500-T/6.3 mobile electric power stations with a capacity of 2,500 KW one year later.

The PAES-1600-T/6.3 mobile gas turbine electric power station consists of two transportable units, mounted in semi-trailer vans towed by a "Ural 377-S" tow vehicle. The AI-20KE engine, the SGS-14-74-6 synchronous generator, as well as the oil and fuel lines and control automation for the synchronous generator are housed in the

TABLE 11.

Parameters	Type of Electric Power Station		
	ESD-50-T/400	ESD-100-T/400	ESD-200-T/400
Capacity, KW	50	100	200
Voltage, volts	400	400	400
Output current, amperes	91	180	360
Power factor	0.8	0.8	0.8
Type of plant	AD-50-T/400	U34A	DGA-100-T/400
Type of engine	1D6-10AD	1D6-150AD	1D12KS
Type of generator	DGS92-4ShchF2	GSF-100M	GSF-200
Fuel consumption, kg/hr	29	56.4	56.4
Oil consumption, kg/hr	1.6	1.6	3.2
Length (with the tow bar), mm	6,940	9,545	9,545
Width, mm	2,580	2,950	2,950
Height, mm	3,290	3,100	3,100
Weight, kg	8,300	12,600	12,600

first semi-trailer van. The 6 KV distribution switchgear, the local control console and the automatic starting equipment are installed in the second van. A provision is also made in this same van for the operator's work position when the electric power station is used by itself. If two to three electric power stations are set up on one side, then the control consoles are moved out to a central point by means of connecting cables 15 m long.

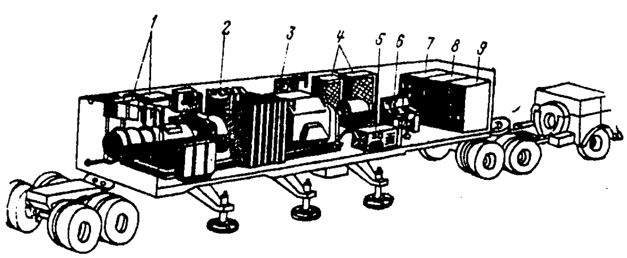

Figure 37. General view of the [mobile automatic gas turbine electric power station] PAES-2500-T/6.3

Key:
1. Block of oil and fuel lines;
2. Noise absorbers;
3. Starting system panel;
4. Generator control cabinets
5. Starting set;
6. Control
6. Control console;
7. Relay cabinet;
8. Cabinet with the 6 KV switch;
9. Cabinet with the transformer for internal power needs.

The PAES-2500-T/6.3 mobile automatic gas turbine electric power station consists of a single block. All of the power station equipment is housed in one semi-trailer van (Figure 37). The three phase 50 Hz AC synchronous generator is driven by a gas turbine engine designed on the basis of the aviation turboprop engine. The gas turbine generator has an automatic start and load connection system after a period of no more than five minutes with subsequent unattended continuous operation. There is protection for all of the main parameters of the engine and synchronous generator. The input unit to the engine is equipped with a noise absorption system. In the case where a heat exchanger is installed, the electric power station can also be used for heat supply.

The Major Technical Specifications of the Generators for Mobile Automated Gas Turbine Electric Power Stations

	PAES-1600-T/6.3	PAES-2500-T/6.3
Type of generator	SGS-14-74-6	SGS-1410-6
Nominal capacity, KW/KVA	1,600/2,000	2,500/3,125
Voltage, V	6,300	6,300
Rotational speed, r.p.m.	1,000	1,000
Excitation voltage, V	80	74
Excitation current, A	308	325

The transportation is provided by MAZ-515 and KrAZ-258 tow vehicles, as well as via railroad, water and air transport.

The gas supply to the electric power stations is accomplished in the following manner. Oil from the collection metering installations, upon arriving in the product depot, is fed through the separation plants, which consists of a volume of 50 m^3 of bulit [sic]. Following the separation plant for the removal of hydrocarbon condensate, oil and water, the byproduct natural gas is fed to a horizontal type gas separator with a volume of 50 m^3, and then via a ground gas pipeline to the area of the electric power station. To clean out mechanical impurities, the gas is passed through capillary filters, installed in the gas pipeline and at the input to the gas turbine engine. To remove condensate along the line, two condensate collectors are installed in the gas pipeline. The gas pressure delivered to the electric power station is stabilized with a regulator.

In 1968-1972, the first PAES-1600-T/6.3 electric power stations were set up, and thereafter, the PAES-2500-T/6.3 electric power station. A gas turbine electric power station was placed in service in 1974 at the Agansk oil field, consisting of three PAES-2500-T/6.3 units; a station was brought on line in 1975 at the Var'yegansk oil field consisting of two PAES-2500-T/6.3 units. Following the connection of the oil fields to the power grid, the gas turbine electric power stations were shut down and are used as emergency and backup electrical power sources.

The operation of gas turbine electric power plants in the fields of the Tyumenskaya oblast has confirmed the advantages they have over steam turbine power trains and diesel electric power stations.

Gas turbine electric power stations also have certain drawbacks along with the positive quality. Operational experience with gas turbine engines has shown that their reliability in the initial introduction stage is poor. Over three years of operation, 50 gas turbine engines failed. Among them are engines which had a service time of up to 100 hours, and only a few engines operated for 7,000 to 10,000 hours; but these engines operated for their standard engine service life aircraft, and then after a major overhaul, were installed in an electric power station.

The major reasons for the failure of engines are the tearing away of the vains of the first compressor stage, the breaking of the joint between the turbine compressor rotor and the reducer, the destruction of the reducer and a number of minor deficiencies (incorrect installation of small drive shaft for the air separator, unsatisfactory adjustment and alignment of station units).

The use of gas turbine electric power stations is especially effective in oil and gas fields where there is an excess of byproduct natural or petroleum gas.

Gas turbine electric power stations designed around aviation turbojet engines have recently become widespread in capitalist nations. Such stations are being most extensively used in the U.S.; their widescale utilization is due to the increase in the nonuniformity of the electrical power load schedules, as well as the necessity for having independently startable power sources in emergency situations.

An American company is producing mobile gas turbine power plants for this purpose with a turbojet engine having a capacity of 15 to 17 MW. The installation is housed in two motor vehicle tractor trailers and consists of two units. The power generation unit is housed in one tractor trailer, i.e., the gas turbine plant with the generator itself, while the auxiliary units are housed in the other: the control and monitoring equipment. The efficiency of the installation is about 23.5 percent.

A mobile electric power station on motor vehicle tractor trailers is quite mobile. Motor vehicle tractor trailers develop a speed of up to 100 km/hr and can be prepared for operation by four technicians in two hours after arriving on site. From the starting of the electric power station to taking on the full load takes three minutes. The weight of the gas turbine unit with the electric power generator amounts to about 38 tons, while the weight of the auxiliary equipment unit is about 18 tons. Each of the tractor trailer vans in which the electric power station units are housed has overall dimensions of 15,100 x 4,100 x 2,240 mm.

A schematic of the electrical power supply to gas fields from gas turbine power stations is shown in Figure 38.

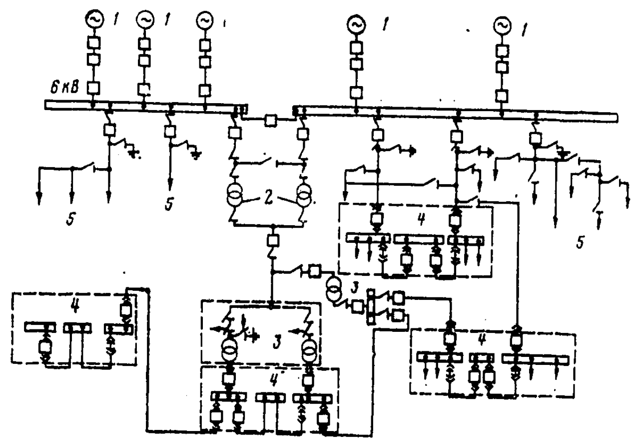

Figure 38. Schematic of the electric power supply for gas fields from mobile automatic gas turbine power stations.

Key: 1. PAES [Mobile automatic gas turbine electric power station] generators;
2. 4 MVA, 6/35 KV transformers;
3. 2.5 MVA, 35/6 KV transformers;
4. Comprehensive gas preparation installations;
5. To the 6/0.4 KV transformers.

Electric Power Transmission Lines

Electric power transmission lines at voltages of 35 and 110 KV are built in oil fields to supply electrical power to group pumping stations, comprehensive collection points, freight depots and other facilities. The constructed 110 KV power transmission lines are turned over for operation by the regional Sverdlovenergo and Tomskenergo power administrations. The operation of the 35 KV power transmission lines is handled by the enterprises of Glavtyumenneftegaz.

The construction of more than 200 km of distribution power lines at 110 KV with 29 substations at 110/6 or 110/35/6 KV as well as 650 km of distribution power transmission lines at 35 KV with 250 substations at 35/6 KV has been planned at the Samotlorskiy field. The 110 KV lines are being built only as two-circuit lines. The 35 KV lines are being built as both two-circuit and single-circuit lines, depending on the electrical power supply configuration adopted. The single single-circuit 35 KV power transmission lines are being built for consumers having a bilateral feed from different 110/35/6 KV substations.

Standardized metal and steel reinforced concrete supports, which are fabricated at central plants, are being used for the open wire 35 and 110 KV lines. The types of the most widespread support poles are given in Table 12.

TABLE 12

Support Poles	35 KV Power Transmission Lines		110 KV Power Transmission Lines
	Steel	Reinforced Concrete	Steel
Intermediate	P-35-1 P-35-2	PB-35-1 PB-35-2	P-110-2 P-110-4
Anchor	U-35-1 U-35-2		U-110-2
Branching	US-110-8		US-110-8
Lowered	US-110-3		US-110-3

Conventional steel support poles with standardized additions 4, 5 and 9 meters high are used for the construction of elevated support poles. Reinforced concrete support poles for 35 and 110 KV lines are used only as the intermediate supports, since the securing of steel reinforced anchor supports in weak soils is difficult. The anchor and special supports are steel. Standardized 35 KV support poles allow for the application of AS type wires with a cross-sectional area of up to 150 mm^2, and up to 240 mm^2 in the case of 110 KV supports.

The petroleum regions of Western Siberia belong to the second region in terms of the wind and ice loading on power transmission lines (the normal wall thickness of rime ice is 10 mm and the wind speed is 25 m/sec). Under these conditions, the overall spans for the standardized support poles amount to 235 - 365 m, depending on the line voltage and the wire cross-section.

Standard type insulators and line fittings are used for the 35 and 110 KV open wire lines. Only glass PS-6-A and PS-12-A insulators are used on the standardized supports. The number of insulators is chosen in accordance with the Regulations for setting up electrical installations, just as for regions with a conventional environment without industrial pollutants. As operational experience with 110 KV power transmission lines at the Samotlorskiy field has shown, the byproduct gas flares, arranged in accordance with existing trandards at a distance of 60 m from the power transmission lines, are sources of intense fouling of the insulation. Because of this, the decision was made to offset the flares at a distance of 300 to 900 m from the 110 KV power transmission lines.

Incorporated in the set of complete insulator strings are the components for fastening the strings to the support pole and the terminals for the wire. The types of parts depend on the wire cross-section, the kind of string (guy or support string) and the line voltage (35 or 110 KV). For example, the guying insulator string of a 35 KV power transmission line for the end supports with AS-35 or AS-50 wires consists of SK-21-1A clamps for securing to the support crossarm, SRS-6-1 hooks for connecting the clamps to the insulator, 5PS-6-A insulators and U-1-6-16 eyes for connecting the insulator to the NKK-1-1 guy wedge terminal clamp for the wire. The line fittings also include standard fastenings for the lightning protection cable and vibration suppressors for the wires and cable.

Lightning protection for 110 KV lines is accomplished by stringing an S-50 lightning protection cable over the entire length of the line. On 35 KV lines, in accordance with the regulations for setting up electrical installations, it is not necessary to string type S35 cable over the entire length and the length of the protected line sections at the entrances to 35/6 KV substations amounts to 1 to 2 km, depending on the point of installation of the dischargers at the substations.

Since the distances between 35/6 KV substations at oil fields frequently do not exceed 2 to 5 km, the lightning protection cable in these cases is also strung over the entire line length for 35 KV lines.

The structural design of the complete 35 and 110 KV type KTPB substations does not allow for fastening the cables at the 35 and 110 KV portals. Thus, the lightning protection cable is terminated at the last support pole of the 35 (110) KV power transmission line. For the protection of the last span of open wire line from the end support to the substation portals, a lightning rod with a height of up to 7 m is mounted on this support pole. The insulation of the wires on the end support is reinforced; for example, the guy insulator strings of the end support for a 35 KV power transmission line consist of 8 insulators.

Open wire 6 (10) KV lines are usually single circuit lines; they are used to provide electrical power to oil extraction installations and other facilities set up around the fields having an overall design load not exceeding 1.4 MVA (for 6 KV power lines) and 2.4 MVA (for 10 KV power lines) per line.

The 6 (10) KV power transmission lines are built along the rows of the operational boreholes. The routes of the power transmission lines are combined with the oil and water pipelines where possible. In this case, combined duct corridors are formed, something which improves the operational conditions for the transmission lines and reduces the area of forest which is cut down. The scheme for a ductwork corridor is shown in Figure 39.

A significant portion of the 6 (10) KV power transmission lines are built using steel reinforced concrete supports fabricated from SNV-2.7 and SNV-3.2 posts. The steel reinforced concrete structural designs for plant fabricated poles are shipped in for the construction of power transmission lines in western Siberia.

Intermediate, branching, corner intermediate and anchor supports, as well as supports for the installation of isolators and supports with cable coupling sleeves are installed on 6 KV open wires lines.

Support poles with cable coupling sleeves are set up at the start of the lines, since the distribution switchgear which feeds the 6 (10) KV power transmission lines have cable outputs in the majority of cases. Intermediate supports consist of one post, a foundation and a cap assembly. Two to three type SNV posts are used for complex supports. Supports with SNV posts are widely used in all regions of the USSR. They are secured in the ground by means of burying them to a depth of 2 m. Such a method of securing the support poles is almost not used in the oil fields of western Siberia because of the complex geological conditions.

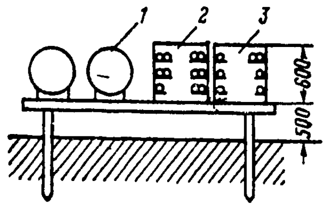

Figure 39. Schematic drawing of the combined laying of cable ducts with pipelines:

Key: 1. Pipes;
2. Cable duct;
3. Cables.

TABLE 13

Support Poles Made of Posts	Suspension Height of the Lower Wire, m	Permissible Band Length, m	Overall Size, m	Reinforced Concrete Consumption per km of Line, m^3
SNV-2.7, buried 2 m in the ground	8.9	85	6.9	5.3
SNV-2.7 on steel reinforced concrete piles	11	85	8.9	16.3
SNV-3.2 on steel reinforced concrete piles	11	100		14.0
M_d = 41 kN · m, on steel reinforced concrete piles	11	130	6.7	10.8

The majority of support poles are securred to piles. Such securing of the supports makes it possible to increase the suspension height of the wire on the supports, which in turn makes it possible to increase the span length and reduce the number of supports per kilometer of line. However, these options are not always exercised in the case where SNV-3.2 type posts are used, and even more, in the case of SNV-2.7 type posts, because of their inadequate strength, and consequently, limitations on the spans because of wind and ice loading. The cnsumption of steel reinforced concrete per kilometer of line, made by various methods, is given in Table 13. Table 13 is compiled for work in the second climatic region using A-95 wire. It can be seen from Table 13 that to achieve the minimum consumption of reinforced concrete with pile securing of the support poles and for a specified post length, posts are needed which are 1.5 times stronger with a maximum permissible moment of M_d = 41 kN · m. Since production has not been set up for steel reinforced supports in the regions where oil fields are located, and the transport capabilities are limited, supports made of spent drilling pipes have become widespread (Figure 40). Steel reinforced supports and supports made of pipes allow for stringing wire with a cross-section of no more than 120 mm^2.

Primarily peg type insulators are used on 6 (10) KV lines with reinforced concrete support poles and support made of pipes. Suspension PS-6A insulators are used only on some complex supports.

Emergency faults in 6 (10) KV power transmission lines are noted almost five times more frequently than on 35 and 110 KV power lines. The major reason for the high incidence of breakdowns in 6 (10) KV power lines is the inadequate accounting for the impact of ice and wind loads during the design and construction of the lines, as well as the phenomena of vibration and "dancing" of the wires. A factor in the increased incidence of breakdowns in 6 (10) KV lines is the use of aluminum wires, especially those with small cross-sections (35, 50 mm^2) as well as the poor reliability of the peg type insulators and the inadequate lightning protection.

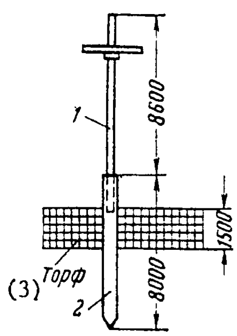

Figure 40. An intermediate support for a 6 (10) KV power transmission line made of used drilling pipes.

Key: 1. 140 x 11 pipe in accordance with State Standard 631-75;
2. Pile;
3. Peat.

A provision is made for the use of improved quality ShF-10G type peg insulators and polyethylene caps to secure the insulators to the pins as well as dispensing the horizontal arrangement of the wires and making a transition to a triangular configuration of the wires on the support poles, the limiting of the use of aluminum wires with a small cross-section (35, 50 mm^2), extending the range of application of steel-aluminum wires, limiting the length of anchor spans, increasing the spacing between wires and the use of new methods of securing the conductors to the peg insulators (a special antivibration type ZAK-10-1 terminal clamp has been developed for this purpose, which should be used in place of wire tying of the conductors to the insulators which is widespread at the present time) to improve the reliability and reduce the incidence of breakdowns of 6 (10) KV power transmission lines. The use of type RVP diode dischargers for the lightning protection of power transmission lines in place of the tubular type RT dishcargers will likewise boost the reliability of the transmission lines.

The standardized steel 35 and 110 KV transmission line supports for oil fields are secured only to piles. The pile foundations for intermediate and anchor support poles consist of one to four piles for each leg of the support and metal gratings. Standardized prefabricated reinforced concrete footings for steel support poles, which are widely used in other regions of the USSR, have not been used in western Siberia because of the fact that watery, weak and frost heaved soils, as well as bogs of considerable depth are universally widespread here.

Thus, bogs with a peat layer of up to eight meters are encountered on some power transmission line routes in the Samotlorskiy field. The securing of intermediate reinforced concrete supports in bogs is likewise accomplished by means of piles. A pile foundation for a 35 (110) KV support consists of 5 reinforced concrete piles from 6 to 12 m long, of which, 4 piles are used for securing the guys (Figure 41). In the case of a shallow peat depth and satsifactory soil characteristics, the intermediate reinforced concrete supports are secured in bored out excavations with the installation of 1 to 3 horizontal stayblocks. Pile pipes of various lengths with a diameter of 400 mm are used for the foundations of supports made of used up drilling pipes. The pipe piles can be subjected to soil corrosion and the service life of these supports has still not been determined, since they have not been in service for more than seven years. To protect them against corrosion, it is proposed that cathodic polarization of the metal piles be employed by means of sacrificial anodes.

The major type of 6 (10) KV open wire lines are current conductors intended for the transmission of large capacities from 110/6 KV substations to the distribution switchgear for KSP [not further defined] and KNS [group pumping stations]. The length of the current carrying conductors is not great, since the effort is made with 110 KV substations in a deep entrance configuration to place them as close as possible to the main loads of the KSP and KNS. The majority of the constructed and planned current conductors have a length of 20 to 180 m, but in a number of cases, the length of the conductors runs to 700-1,500 m (for example, the current conductors for the central collection points of the Samotlorskiy and Fedorovskiy fields).

The permissible current level for a current conductor amounts to 240-2,500 amps, the number of type ASO conductors per phase is 1 to 3 and the cross-section of the conductors is 240 to 600 mm^2. Steel portals 7.5 m high with pile foundations and supports 3.9 m high for the portions of the conductor passing under 6-110 KV power transmission lines are used for stringing the wires. The current conductor sections which are constructed on low supports are fenced off by a metal mesh enclosure with a height of 2 m. The spacing between the portals runs up to 30 meters. The wires are secured to the portals by means of guy insulator strings made of PS-6-A or PS-12-A suspension insulators. Each string consists of two insulators. A special fitting is used to fasten several conductors to one string. On low supports, the conductors are fastened to ONS-20-2000 or ONSM-10-2000 peg insulators. Spacers are installed with a step of 1.5 m over the entire length of each phase of a current conductor. Lightning protection is realized using diode RVP type dischargers at both ends of the current conductor as well as by the installation of individual separate lightning rods along the entire current conductor. The point of installation of the lightning rods is chosen so that the entire current conductor structure is incorporated in the lightning protection zone. Metal and reinforced concrete supports up to 30 m high are used as the lightning rods. A schematic drawing of a current conductor and its lightning protection is shown in Figure 42.

The cross-sectional area of the conductors, the number of line circuits and the permissible open wire line length are determined during the planning of the

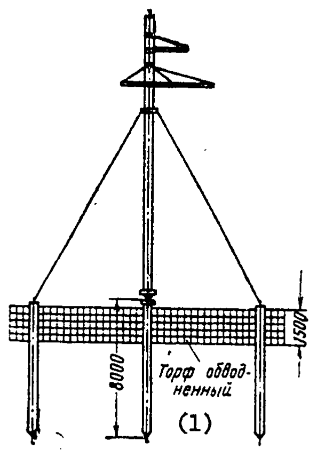

Figure 41. The securing of an intermediate steel reinforced 35 KV support pole.
Key: 1. Waterlogged peat.

electrical power supply configuration for a field, taking into account the prospects for a growth in the loads in step with the exploitation of the deposit. For this reason, when planning a line, the cross-section of the wires and the number of circuits are taken from the approved electrical power supply plan. For the correct spacing of supports along the route, to provide for the standard set distances to the surface of the ground and intersecting engineering structures as well as to determine the erecting sags, a mechanical design is made for the wires and cables of an open wire line on a computer using a program compiled in accordance with the Governing Instructions for the Design of Open Wire Power Transmission Line Conductors and Cables.

It is assumed in the design calculations that the maximum wind speed is 25 m/sec, the thickness of the ice cover wall is 10 mm, the minimum temperature is -55 °C, the maximum temperature is +35 °C and the average annual temperature is -5 °C.

Cable lines at voltages of 35 and 110 KV are not used in oil fields. Cable lines at voltages of 0.4, 6 or 10 KV are employed for the internal electrical power supply for facilities. At large complex collection points, the overall number of cables and the length of cable routes is quite considerable. For example, at KSP 6 of the Samotlorskiy field, the overall number of power cables at all voltages is 175, the total cable length for all cross-sections is 35.4 km and the length of the routes of cable trestles is 1.8 km.

Underground laying of the cables in trenches was used in the initial stages of mastering the deposits. Experince with the laying and operating of underground cables demonstrated the complete unacceptability of such a method for the construction of cable lines, since in the construction of corridors of ducts, the soil structure is disturbed as a result of laying numerous pipelines and the ground is weakened and becomes waterlogged. Cables which are run underground are frequently damaged by construction and transport vehicles. Numerous sites are covered with shipped in earth on top of the peat layer and other weak soils during the construction. If the cables are run in the ground prior to the final cover fll to the design marker and prior to the completion of the equipping with services and facilities of a territory, then they consequently prove to be at a great depth (up to 3 m) from the surface and axcess to them is impossible. For this reason, underground cable laying on the sites of facilities has been almost completely terminated and the major cable routes are run above ground. At some facilities, the cables are run in ducts. The cable ducts are mounted on the low supports of

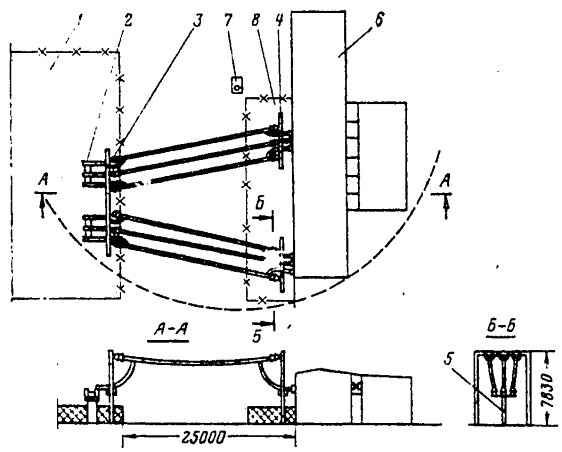

Figure 42. A 6 KV current conductor.

Key: 1. 110 KV substation;
2. Disconnect switch;
3. Double portal;
4. Portal;
5. Post;
6. 6 KV distribution switchgear;
7. Lightning rod;
8. Fence enclosure.

heat routes run above ground. The duct is a standard type cable channel, only not burried. The cable structures usually employed for cable channels (shelves and props) are installed in the ducts. The ducts have easily removable covers; their support structures are metal, while the housing is made of an incompbustible material, for example, asbestos cement sheets.

Since the ducts are usually not built at the same time, and it is necessary to run cables prior to the placing of the first stage facilities in service, the construction of cable lines in conjunction with other conduits has proved to be inconvenient. At the present time, special trestleworks intended only for running cables are constructed in all cases on the sites of facilities.

Impassible cable support trestles are used which are serviced by means of mobile transport vehicles. The support trestles consist of single post supports, longitudinal runs, cable structures and sun shades for protection against solar radiation. The suspension height for the lower cable is taken as 2.5 m above the surface of the ground and 4.5 m when intersecting thoroughfares on the site.

According to the existing norms, the major structures for support trestles should have an ultimate fire resistance of no less than 12.75 hr, and for this reason, reinforced concrete or plastered metal supports and longitudinal beams should be used for their construction. Metal support trestles made of pipes and roled steel have become the most widespread in practice. Conventional posts and shells installed on longitudinal beams at a spacing of 1 m are used as the cable structures for support trestles.

Cables for all purposes are run on the support trestles, where the majority of the cables are intended for suppling electrical power to explostion hazardous installations. In accordance with the requirements placed on the protection of explosion hazardous installations against the accumulation of a high potential, against electrostatic and electromagnetic induction during lightning discharges, as well as because of the simplified structures design of the support trestles, primarily armored type SBG, VVBG, AABG and AVBGR cables are used for cable laying on the support trestles. The cable structures and all of the support poles for the trestles are grounded. Specially run steel bands are used for grounding on steel reinforced concrete support trestles. Operational experience with cable trestles has demonstrated their high reliability and convenience in operation as well as when repairing and replacing cables.

After the determination of the overall length of 6 (10) KV open wire lines and the overall length of the 6 (10) KV cable network (entrances, inserts in open wire lines, taps off to electric motors and 6/0.4 KV transformer substations), which are connected to each 35/6 or 110/6 KV substation, the level of the single phase short circuit current to ground in the 6 KV network with an insulated neutral is calculated. The capacitive currents are computed from tables which contain precalculated values of the capacitive currents per unit of line length (open wire or cable). If the single phase short circuit current to ground in the 6 (10) KV network for a feed substation exceeds 10 amps, then it is necessary to provide for the installation of arc suppressing reactors which compensate for the capacitive current and which reduce the level of the capacitive single phase short circuit current down to 10 amps.

CHAPTER EIGHT. TRANSFORMER SUBSTATIONS, SWITCHGEAR, RELAY PROTECTION AND AUTOMATION

Transformer Substations and Switchgear

Substations at 110/6, 110/35/6 and 35/6 (10) KV with capacities of from 1 x 1.0 up to 2 x 40 MVA are used to provide electric power to oil fields. The traditional practice in the construction of substations from individual electrical equipment in outdoor distribution switchgear (ORU) and the construction of buildings for cellular distribution switchgear (ZRU) under western Siberian conditions is unacceptable because of the reduced timeframes for the construction and the inadequate production base for the fabrication of the structural design.

In setting up the equipment for the oil fields of western Siberia, complete transformer substation packages (KTP's) for all voltages have found application. The high degree of factory readiness of KTP's, the capability of shipping them with any transport and the comparatively small volume of installation and setup work were responsible for the widescale use of KTP's. For example, the construction of 29 substations at a voltage of 110 KV was provided at the Samotlorskiy field, and of them, 26 were complete packages with the euqipment in plant fabricated units. At the Mamontovskiy, Pravdinskiy and other fields, all of the 110 and 35 KV substations are complete packaged units.

The circuits and structural designs for fully equipped modular transformer substations (KTPB's) were developed by the Kuybyshev "Elektroshchit" plant in conjunction with the Odessa affiliate of the Orgenergostroy Institute. The set of circuits for the primary connection of 110 and 35 KV complete modular transformer substation packages contain 10 different circuits, of which 5 have found applications in oil fields (circuits Nos. 8, 8N, 9, 32 and 35).

Circuit No. 8 is used for the 35/6 (10) KV complete modular transformer substation package and takes the form of a bridge made of three 35 KV switches and disconnectors at the entrance to the power transformers (Figure 43). Circuit No. 8N takes the same form as circuit No. 8, but with the addition of voltage transformers at the power transformer entrance. Circuit No. 9 contains 35 KV switches at the entrance for the power transformers, a 35 KV switch in the jumper bridge and permits the connection of four 35 KV lines, where one or two of them is used as the entrances (Figure 44). The 110/6 KV complete modular transformer substation package using circuit No. 32 is designed for dual winding power transformers and has dividers and a jumper bridge made of two disconnectors between the 110 KV circuits on the 110 KV side(Figure 45). A complete modular transformer substation package with 110/35/6 (10) KV triple winding power transformers is designed using circuit No. 35. On the 110 KV side, circuit No. 35 is similar to circuit No. 32. On the 35 KV side, one can connect four outgoing lines, and there is also an ordinary 35 KV bus system sectionalized with a switch.

The plan supplies the following KTPB equipment in complete packages:

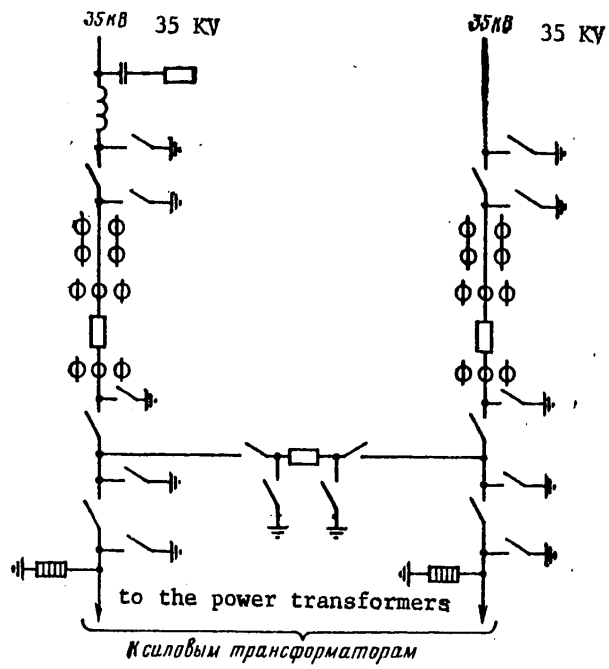

Figure 43. Circuit No. 8 for a 35/6 (10) KV fully equipped modular transformer substation package.

--110 and 35 KV outdoor distribution switchgear, consisting of units, in each of which there is installed from one to three pieces of equipment (switches, disconnectors, voltage transformers, etc.); there are twelve 110 KV blocks and twenty-six 35 KV blocks in all, from which the substations for all 10 circuits are put together;

--A 6 (10) KV distribution switchgear unit made of type K37 KRUN [not further defined] cells; cabinets with relay equipment are located in the control corridor;

--A heated cabinet with electric heating for housing the communications and remote control equipment;

--Rigid and flexible 110, 35 and 6 (10) KV buswork; sections of flexible buswork are made with A-70, A-120 and AS-300 aluminum conductor; the rigid 110 and 35 KV buswork is fabricated from aluminum pipes;

--A cabinet for storing the fire fighting equipment and protective gear;

--Metal suspension cable pans for running power and control cables through the substation site;

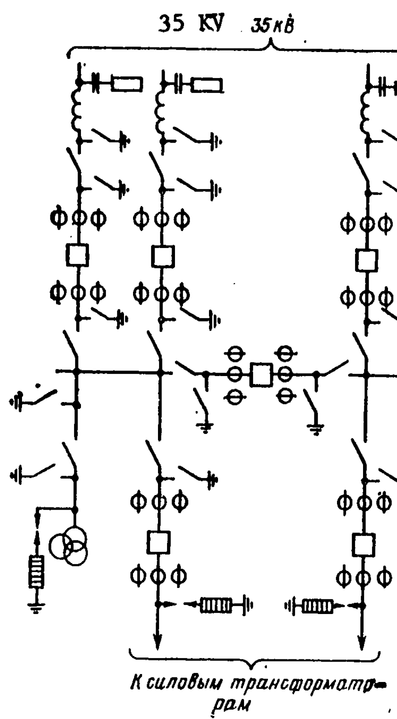

Figure 44. Circuit No. 9 of a 35/6 (10) KV fully equipped modular transformer substation package.

--Lights for illuminating the outdoor switchgear and the KRUN.

The power transformers and internal power requirement transformers, power and control cables as well as the communications and remote control equipment and hardware are not included in the overall complement of the KTPB [complete modular transformer substation package].

Transformers with voltage regulation under load with a capacity of from 1 to 16 MVA can be used in the KTPB for 35/6 (10) KV; transformers from 2.5 to 16 MVA can be used in the KTPB for 110/6 (10) KV and transformers with a capacity of up to 40 MVA can be used in the KTPB for 110/35/6 (10) KV. Two transformers for internal power requirements with a capacity of 63 KVA at a voltage of 6 (10)/0.23 KV are installed in the KRUN cabinets. A general view of a 110/6 KV KTPB is shown in Figure 46.

Equipment of the U design series is used in the outdoor distribution switchgear for the 110 and 35 KV KTPB: S-35M-630-10 spring driven 35 KV switches, type RNDZ 110 KV disconnectors, OD-110/630 isolators and type KZ-110 short circuiting

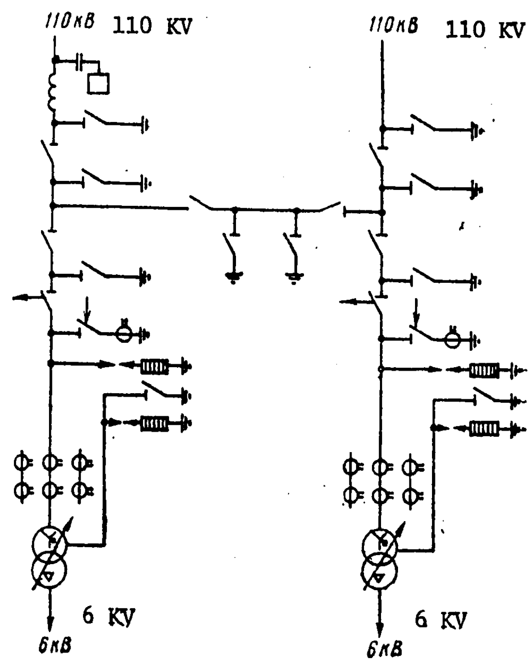

Figure 45. Circuit No. 32 for a 110/6 (10) KV KTPB [complete modular transformer substation package.

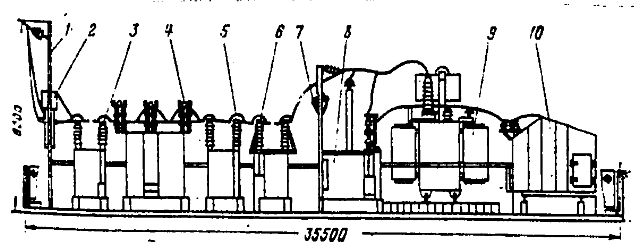

Figure 46. General view of circuit No. 32 for type KTPB 110/6 KV substations.

Key: 1. 110 KV entrance portal; 2. Barrier trap; 3. B-110-3/2.5N disconnector block; 4. B-110-4/2P disconnector block; 5. B-110-4/2.5 disconnector block; 6. B-110-5/2.5 isolator unit; 7. Lighting installation; 8. B-110-1K short circuiting unit; 9. 110/6 KV transformer; 10. K-37 type KRUN [not further defined].

devices. The 6 (10) KV distribution switchgear, which consists of K-37 cells, does not have any kind of heating or preheating. Installed in the K-37 cells are VMPP-10 10 KV switches for nominal current levels of 630, 1,000 and 1,500 amps with a built in spring drive, having a maximum disconnect current level of 20 KA. The dynamic current strength of the 6 (10) KV distribution switchgear is 52 KA. The K-33 cells with VMP-10E switches (nominal current level of 3 KA) are used as the entrance and sectional cells for the 6 (10) KV KRUN for substations with capacities of 25 and 40 MVA. The greatest number of KRUN cells which can be supplied by the factory is 16 (included in this number is also a cabinet for communications equipment). There are no more than five outgoing 6 (10) KV lines.

The dimensions of the substations in a plane view (around the outline of the fencing enclosure) are as follows (in meters): the 35 KV KTPB using circuit configuration No. 8, 28 x 32; the 35 KV KTPB using circuit configuration No. 9, 30.5 x 32, the 110/6 KV KTPB using configuration No. 32, 28 x 35.5; and the 110/35/6 KV KTPB using configuration No. 35, 40 x 62.5. Only pile foundations are used for the installation of KTPB's in the oil fields of western Siberia. The lightning protection for the KTPB's is accomplished by installing lightning rods on the 110 and 35 KV end supports or indidually standing lightning rods.

The KTPB substations in the majority of cases do not have service personnel permanently attending them. The capability of transmitting "defect" and "emergency" signals from the substation has been provided via a high frequency channel using the 35 or 110 KV power transmission lines. The remote signaling equipment is installed in a heated cabinet, which is located together with the KRUN 6 (10) KV, and the factory supplies special units in the complete set with the 35 and 110 KV outdoor distribution switchgear for the installation of the coupling capacitors and barrier traps. Telephone communications is possible both via the high frequency channel and through the telephone network of the oil field.

The present day structural design of KTPB's does not fully meet the requirements for operation under western Siberian conditions. For this reason, a KTPB structure was developed in a KhL design with type K-42 cells.

The ST-7 type substation from the Polish Peoples Republic, designed for outdoor installation, are of a U design. The following units are included in the complete set for a single transformer substation: high frequency telephony, remote automation and remote signaling; 35 KV entrance cells; a power transformer with a capcity of 4 MVA; 6 (10) KV distribution unit; capacitors for increasing the power factor. Units with the equipment partially removed can be transmitted by all kinds of transport and hauled on their own skids by means of a tractor.

The transformer unit has the greatest weight (13,100 kg). The 6 (10) KV distribution switchgear is broken down lengthwise into two sections during shipment, which are easily joined together at the installation site. Buswork of copper and aluminum buses with a rectangular cross-section, a transformer for internal power requirements and cables for interconnecting individual units are included in the complete substation set. A general view of the substation is shown in Figure 47. The power transformer has voltage control devices for operation under load, as well as a voltage control range of $\pm 2 \cdot 2.5$ percent (without a load).

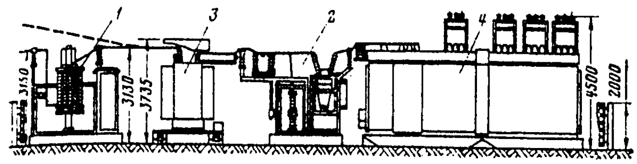

Figure 47. General view of the type ST-7 35/6 KV transformer substation.

Key: 1. High frequency telephony, remote automation and signaling units;
2. 35 KV entrance block;
3. 35/6 KV transformer unit;
4. 6 KV distribution switchgear.

The 6 (10) KV distribution switchgear has an external housing and doors made of metal structures, and kept warm with a thermal insulating material. Cells with carriages are installed in the distribution switchgear units, which roll in the service corridor. The transformer for the internal power requirements with a capacity of 63 KVA, 6 (10)/0.23 KV, is installed in the internal power load cell along with the distribution panel.

lectric heating of the tanks and the 35 KV switch drive, the communications equipment cabinet and all cells of the 6 (10) KV distribution switchgear is employed in the substation. Both manual and automatic control of the electric heating is possible: automatic from temperature and humidity sensors. Switches with a nominal current level of 630 A and a disconnect capacity of 150 KVA at 6 KV are installed in the cells of the 6 (10) KV distribution switchgear. The dynamic current strength of the electrical equipment of the 6 (10) KV distribution switchgear amounts to 63 KA.

In terms of the electrical circuitry, the 6 (10) KV switchgear unit has three variants: with two cable and four open wire outgoing lines and without a sectionalized switch; with two cable and three open wire outgoing lines and one cell of a sectionalized switch with an AVR [automatic standby switching] device using a sectionalized switch; and with a cell of a sectionalized switch without an AVR device. The first variant is used at a single transformer substation, for which no expansion is planned to a two transformer substation.

A two transformer substation is formed from two single transformer substations by means of joining two 6 KV distribution switchgear units together (the second and third variants) using a bus bridge and connecting the 35 KV entrance units together. On the 35 KV side, when the units are connected, a jumper bridge is formed from the two disconnectors (Figure 48). Each disconnector is installed by the manufacturing plant in the 35 KV entrance unit only for substations which

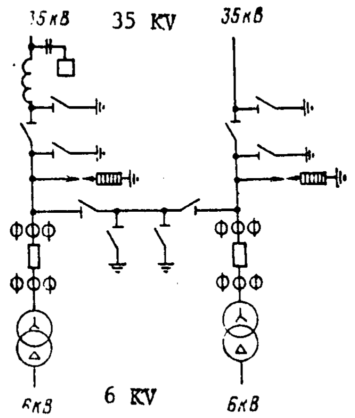

Figure 48. Schematic for a ST-7 two transformer 35/6 KV substation.

allow for the possibility of expansion to two transformer substations. Cabinets for control of internal power requirements and central signaling are installed in the 6 KV distribution switchgear units. The connection of the secondary circuits of the two 6 KV switchgear units provides for the action of the automatic standby switching using the sectionalized 6 KV switch and the requisite interlocks against erroneous actions of the personnel.

The dimensions of the ST-7 substation units are less than the dimensions of the 35/6 KV KTPB substations. The delivered equipment complement of the ST-7 substation is greater than that of the KTPB substations, since the power transformer, the transformer for internal power requirements and the cables are included within the scope of the delivered ST-7 substation.

The ST-7 substations have 6 (10) KV distribution switchgear which is more convenient in operation, since the temperature is maintained in the switchgear unit and therefore is less dependent on the ambient temperature. The ST-7 substations are also more convenient for the installation work.

The KTPB substations permit the installation of transformers of all capacities from 1 to 16 MVA, while the ST-7 substation has a fixed transformer capacity (4 MVA). The limitation on the transformer capacity is related not only to their delivery as a complete package, but also to the use of 6 KV entrance switches with a current level of 630 amps. In contrast to the ST-7 substations, the KTPB type substations have all of the requisite equipment for the installation of transformers with voltage regulation under load, because of which the maintenance of the requisite voltage is assured in all operational modes of the 35 KV network. The KTPB substations have a more sophisticated circuitry on the 35 KV side (a jumper with a switch between the 35 KV circuitsand the automatic standby switching device).

Because of the specific features enumerated above, it is recommended that KTPB substations with a capacity of 1 to 16 MVA be used, especially the KhL design, for the permanent electrical power supply for group pumping stations, as well as in all cases where two-transformer substations are needed.

The ST-7 two-transformer substations are to be used to provide electrical power to all facilities where the capacity is no more than 2x4 MVA as well as given the condition that the lack of voltage regulation under load is of no great importance.

Separately standing buildings to house the 6/0.4 KV substations are built on the sites for facilities at oil fields because of the presence of a large number of explosion hazardous installations. The substation buildings are layed out at the minimum permissible spacing from explosion hazardous installations. In accordance with the existing norms, cubicle substations can be positioned at a distance of 40 m from storage tanks and other tanks with highly flammable liquid, and at a distance of 10 m from other explosion hazardous outdoor installations. The use of transformers installed in the open in these cases is not advantageous, since they should be installed at a distance of no less than 60 m from storage tanks and 25 m from other explosion hazardous outside installations. Add-on and built in substations are used at nonexplosion hazardous installations, for example, at group pumping stations and foam generator stations.

The buildings for separately standing 6/0.4 KV substations are put together from heated metal panels, hung on a metal framework. The dimensions of the building in a plan view run from 6 x 6 to 9 x 18 m. TP-10-2 electric heaters with a capacity of 1 KW each are used to heat the buildings in the winter. The overall capacity of the electric heaters for one building amounts to about 10 KW. Used as the substations are fully equipped transformer substations with an internal installed capacity of from 2 x 250 up to 2 x 1,000 KVA. Two-transformer substations are needed, since the majority of electrical recipients belong to the second category in terms of the level of electrical power supply reliability, while the fire fighting systems of the facility belong to the first category.

The use of complete transformer substations, fabricated by various plants in the USSR, as well as those obtained from the Czechoslovakian SSR and GDR, makes it possible to build a complete transformer substation building without internal barriers, and in this case, there is no need for individual chambers for the transformers and rooms for the 0.4 KV switchgear. Special transformers with strengthened structural design for the tank are used in this case for the complete transformer substation.

The outgoing lines of the complete transformer substations, which are equipped with automatic switches or breakers, are used to power only those electric power recipients, who have their own starting equipment. To power explosion hazardous modular installations, for example various pumping stations, a station control panel with the starting and protective equipment for each electric motor is housed in the building for the complete transformer substation. Large unit station control panels in an outdoor design made of standard BU-5000 and BU-8000 series blocks are supplied as complete sets by the plants. Covered main line buswork is used to connect the complete transformer substations to the station control panel.

Relay Protection and Automation

Relay protection in electrical circuits is intended for the rapid and selective disconnection of damaged equipment and power transmission line sections. Automation is used in electric power networks to prevent emergencies, for the rapid connection of standby power for electrical installations as well as the rapid restoration of normal operation of electrical equipment following short term interruptions in the power supply. The kinds of protection used for various facilities are regulated by the Governing Instructions for Relay Protection and Regulations for Setting Up Electrical Installations.

Standard circuits have been developed and are used for relay protection and automation systems, while relay equipment is supplied in complete sets with the KTB substation and the cubicles for the 6 (10) KV complete distribution switchgear, and is housed in special relay cabinets.

The major types of relay equipment supplied in complete sets with KTPB's and KRU's [complete set of distribution switchgear], are enumerated in Table 14.

Separately standing control panels with the requisite set of relay equipment are ordered for those kinds of protection and automation which are not supplied in complete sets by the KTB and KRU manufacturing plants. Included among them are counter-emergency automation, automatic motor starting, field current protection panels, etc. Only the specific features of the relay protection and automation devices in the circuits for the electric power supply of oil field facilities of western Siberia are treated here.

The differential protection of transformers for KTPB 110/35/6 KV substations where entrance and line swithces at 35 and 6 KV are present acts to disconnect the entrance 35 and 6 KV switches and connect the short-circuiting device. Maximum current protection with an initial time delay stage likewise acts to disconnect the 35 and 6 KV entrance switches. Many 110/35/6 KV substations with a capacity of 25 and 40 MVA are built with simplified 6 KV distribution switchgear and do not have the 6 KV entrance and line switches. In this case, the entrance switches for the 6 KV switchgear of the group pumping stations are used for the differential and maximal current protection of the power transformer. In this case, included in the protective zone of the transformer is a current conductor from the substation to the 6 KV switchgear of the group pumping station which is up to 180 m long. The relay protection equipment for the transformer is located in the substation (supplied in a complete set with the substation). The current transformers of the entrance cells of the 6 KV switchgear for the group pumping stations are used for the current protection circuits and voltage regulators under load for the power transformers. The entrance cells of the 6 KV switchgear and the relay cabinets of the substations are connected by a monitor cable up to 180 m long, run along the route of the current conductor.

The entrance switches for the 6 KV switchgear, with the action of the protection circuitry, are disconnected by the operational current of the 6 KV switchgear of the group pumping stations. If the 6 KV switchgear consists of K-XII cells, the power from capacitors charged beforehand is used for the disconnection. When putting together the complete 6 KV switchgear set from K-X cells, a storage battery serves as the operational current source.

The 6/0.4 KV complete transformer substations, which are protected against short circuits by fuses, are connected to the 6 KV electrical networks intended for the power supply to groups of operational wells. It is essential for selective protective action that the fuses burn out before the actuation of maximum current protection for the line to the supply substation. In designing the 6 KV power transmission lines for oil fields, the short circuit currents are calculated, as well as the maximum current protection settings and a graph is plotted with a matching of the setting for this protection to the characteristics of the complete transformer substation fuses.

The procedure for the design calculation is as follows. First, the minimum current level for a two-phase short circuit ($I''^{(2)}_{s.c.\ min}$) is determined for the most remote complete transformer substations of the various capacities. Then the current level for the actuation of the protection ($I_{s.c.}$) is determined from the condition for the minimum permissible protection sensitivity (the sensitivity coefficient K_s should be no more than 1.5):

$$I_{s.c.} = I''^{(2)}_{s.c.\ min}/K_s$$

and the offset of the protection level from the nominal current level of the line I_{load} is checked taking into account the reliability factor K_H and the drop-off to pick-up ratio of the relays K_B:

$$I_{s.c.} \geqq (K_H/K_B) I_{load}.$$

TABLE 14

Designation of the Relay Equipment	Types of Relay Equipment for Substations: 110/35 KV KTPB	Type K-37 KRUN	KRU of the K-XII and K-X types
Differential protection relay for transformers	RNT-565, DZT-11		
Differential protection relay for motors			RNT-565
Maximum current protection relay	RT-40	RT-40	RT-40
Automatic standby switching relay			RPV-58
Time delay relay	RVM-12	RVM-12	EV-124, EV-133
Reverse sequence voltage relay	RNF-1M	RNF-1M	RNF-1M

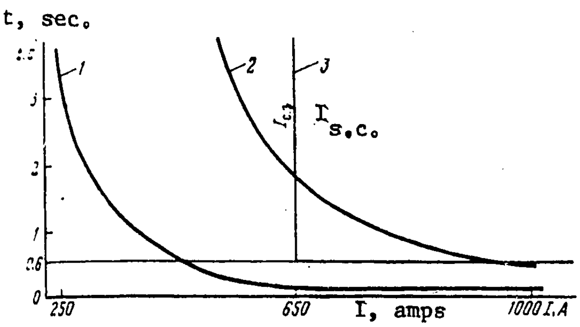

Figure 49. Graphs showing the matching of the fuse characteristics to the maximum current protection for a line.

Key: 1. Time--current characteristic for a fuse rated at I_{load} = 50 A;
2. The same, for a fuse rated at I_{load} = 100 A;
3. The characteristics for the actuation of the maximum current protection.

The graphs for matching the protection for one of the lines is shown in Figure 49. Selectivity in the protection response is not assured for a transformer with a capacity of 630 KVA having a 100 ampere fuse.

In accordance with Regulations for Setting Up Electrical Installations, it is sufficient to have maximum current protection with a time delay of no more than one second for transformers with capacities of 1,600 KVA and a voltage of 35 KV. However, for 6/0.4 KV transformers with a capacity of 25 to 1,000 KV, fed via cable lines from high power 110 KV substations, maximum current protection and current cutoff are used simultaneously in actual practice. The current cutoff is necessary primarily so as to not increase the cross-sectional area of the 6 KV supply cables based on conditions of thermal resistance to the action of short-circuit currents. For example, the nominal current level of a 6/0.4 KV transformer with a capacity of 400 KVA is 38 A. When a complete transformer substation package is powered from a 110 KV substation with a capacity of 25 MVA via a shorted cable line, the level of the steady-state short circuit current is approximately 12 KA. If the time delay for the maximum current protection is 0.6 seconds, then the cross-section of the supply cable, based on the thermal stability condition, is 120 mm^2. However, if there is current cutoff, then one can be limited to a cable with a cross-section of 70 mm^2.

The maximum current protection on the 0.4 KV side of the transformer is standby protection, and its setting is chosen so that the transformer is disconnected by the action of the maximum current protection on the 6 KV side when the main protection fails on the 0.4 KV side. The actuating current for this protection is governed by the condition for the offset of the nominal current level of the transformer, taking a reliability factor into account. In this case, the protection sensitivity coefficient should be no less than 1.5. The sensitivity coefficient is determined from the formula:

$$K_s = I''^{(2)}_{s.c.\ min}/I_{s.c.}$$

The current cutoff setting is chosen from the condition for offsetting the cutoff due to short circuits following the transformer (i.e., the current cutoff should not actuate in the case of short circuits on the 0.4 KV side, taking the reliability factor into account):

$$I_{s.c.} = K_H I''^{(3)}_{s.c.\ max},$$

where $I''^{(3)}_{s.c.\ max}$ is the maximum current level of a three-phase short circuit on the 0.4 KV side of a 6/0.4 KV transformer.

Two-transformer 35.6 KV substations of completely equipped modular transformer substation packages are outfitted with an automatic standby switching device both on the 35 KV side and on the 6 KV side. In the normal mode, the sectional 35 and 6 KV switches are cut off, and the transformers operate separately on their own 6 KV bus sections. In the case of an emergency disconnect of one of the supply 35 KV power transmission lines, the minimal voltage protection cuts off the 35 KV entrance and the automatic standby switching device turns on the sectional 35 KV switch. Both transformers are then connected to one (undamaged) 35 KV line and continued to operate normally with the disconnected sectional switch on the 6 KV side. In case the voltage disappears on one of the 6 KV bus sections, for example, in case the protection disconnects a damaged transformer, the automatic standby switching actuates on the 6 KV side, i.e., the 6 KV input of the damaged transformer is disconnected and the sectional 6 KV switch is turned on. The entire load is powered from a single transformer. If the transformer overload in this case does not exceed the permissible level, there is no need of disconnecting a portion of the consumer.

The presence of automatic standby switching in 35/6 KV substations requires counter-emergency automation devices.

In emergency operational modes of a power system, for example, with the disconnection of a portion of the 220 and 500 KV supply power transmission lines, the counter-emergency automation should disconnect a portion of the load to maintain the stable operation of the power system. In those fields where the distribution network is made with two-circuit lines at a voltage of 35 KV, the automation for system load relief disconnects one 35 KV power line circuit at the supply substation and the second circuit remains connected.

Since the substations for the users are two-transformer types and have automatic standby switching devices, the simple disconnection of a line does not lead to load relief for the supply substation, since the emergency standby switching automation switches the power of the entire load over to the disconnected 35 KV line.

The counter-emergency load relief automation units which are installed at the 35/6 KV substations of the users, should determine the reason for the disappearance of voltage in the 35 KV line. If the voltage has disappeared because of damage to the line, the automatic standby switching actuates without the disconnection of consumers. If the voltage has disappeared because of the disconnection of a damaged line at the supply substation for the purpose of easing its load, then with the actuation of the automatic standby switching, some of the consumers should automatically disconnected.

To determine the reason for the disconnection of the 35 KV power transmission line, a sectional switch on the 6 KV side is automatically switched on while the input 35 and 6 KV switches remain turned on (the minimal voltage protection for the 35 KV entrance is disabled). A voltage is fed into the disconnected 35 KV line from the second circuit of the 35 KV power transmission line through power transformers and 6 and 35 KV entrance switches. If the line is damaged, i.e., a short circuit has occurred on it, a special sensitive reverse sequence voltage protection actuates and the load is not removed from the substation. If the line is not damaged, but was disconnected for the purpose of providing load relief for the supply substation, then the reverse sequence voltage protection does not actuate. In this case, the supply lines for the group pumping station (no less than 50 percent) of the entire load are automatically disconnected. The remaining lines which power the petroleum extraction facilities are not disconnected.

The relay circuitry for the counter-emergency load relief automation, following the disconnection of the group pumping station, enables the action of the automatic standby switching on the 35 KV side and acts to disconnect the sectional 6 KV switch. An illustrative schematic of the primary connections following the action of the automation is shown in Figure 50.

Automatic standby switching is likewise used in two-transformer 6 (10)/0.4 KV substations. Complete substation packages with a capacity of 2 x 400 to 2 x 1,000 KVA with entrance and sectional type AVM automats have an automatic standby switching device on the 0.4 KV side. When the voltage is lost in one of the 0.4 KV bus sections (for any reason), the entrance automat disconnects and the sectional automat turns on, after which the entire load of the complete transformer substation is powered from a single transformer. Two-transformer 6/0.4 KV substations, consisting of single complete transformer substations with a capacity of 2 x 250 KVA, as well as substations put together from individual transformers with capacities of 25 to 160 KVA, can also have automatic standby switching where necessary. Such substations usually operate in an automatic substitution mode for the working and standby transformers. Normally, both transformers are connected to the 6/(10) KV side, but one of them is disconnected on the 0.4 KV side. The 0.4 KV buses are not sectionalized; when voltage is lost on the 0.4 KV buses, the working transformer is disconnected by a standard type BU-8253 control station; contactors are used as the switching apparatus. The stations are manufactured for a nominal current level of from 80 to 250 A.

Automatic repeat connection is primarily used for open wire power transmission lines at all voltages. Self-eliminating short circuits are possible on open wire 6-35 KV lines, for example, in the case of thunderstorm discharges. In the case of a short circuit on the line, the switch of the supply substation is disconnected by the maximum current protection. The switch is again actuated after a time delay of 0.5 to 5 seconds. If the short circuit on the line is not eliminated, then the line is again disconnected.

There is a large number of substations without entrance disconnect switches in the 110 KV networks, where isolating switches are used in their place. The protection for the transformers of such substations acts to disconnect the switch at the supply substation following the creation of a short circuit on line. A KZ-110 short circuiting apparatus serves to produce the short circuit. After the disconnection of the 110 KV line switch, the isolating switch of the damaged transformer is cut off during a zero current pause. The restoration of the power to the remaining transformer, connected that same line, is accomplished by the action of the automatic standby switch at the substation which powers the 110 KV line. The time delay in the automatic standby switching should be sufficient to allow time for the isolating switch to disconnect the damaged transformer. In the 110 KV distribution network for oil fields, many synchronous group pumping station motors with a capacity of 1,250 to 4,000 KW are connected to the 110 KV substation. With the actuation of the short circuiting device at one of the substations and the disconnection of the power transmission lines from the motors powered from all of the substations connected to the given line, the short circuit point is powered during the run-out time until the quenching of the field of the motors. This can lead to the failure of the isolating switch to disconnect the damaged transformer and to the unsuccessful automatic standby switching of the line because of the lack of a current free pause in the automatic standby switching cycle. In order to eliminate the delivery of power to the short circuit point by synchronous motors, fast acting protection is employed which acts to disconnect the motors. The circuit for protecting against power delivery to a short circuit fault is shown in Figure 51.

Following the disconnection of the 110 KV line, the frequency begins to fall off as a result of the reduction in the speed of the motors. When the frequency drops to 48-48.5 Hz, frequency relay K3 actuates, as well as intermediate relay K7 and power relays K_1 and K_2 turn on, the current windings of which are inserted in the circuit of transformer Tr_1. When power is routed from the substation into the disconnected line, because of the supply of power by the motors, power relays do not actuate, relay K_8 is turned on through the break contact of relay K_6 and the contact of relay K_7. After a time delay of 0.3 to 0.5 seconds, the sliding contact of relay K8 acts to disconnect all of the motors. If the frequency reduction is not due to the disconnection of the 110 KV line, but has occurred as a result of power system overloads, then the power flow is routed

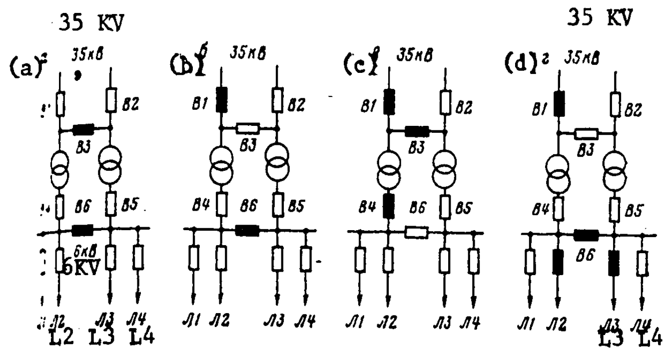

Figure 50. Schematic showing the action of automatic showing the action of automatic standby switching and counter-emergency automation for a 35/6 KV substation.

Key: a. Substation circuit in the normal mode;
b. Circuit following the action of automatic standby switching on the 35 KV side;
c. Circuit showing the aftereffect of the automatic standby switching on the 6 KV side;
d. Circuit showing the aftereffect of the counter-emergency automation (substation load relief);
e. B1, B2: 35 KV entrance switches;
B3: 35 KV sectional switch;
B4, B5: 6 KV entrance switches;
B6: 6 KV sectional switch;
L1-L4: outgoing lines.

from the line to the motors; then relays K_1 and K_2 actuate, contact K_6 opens in the circuit of K_8 and the motors are not disconnected, i.e., the false actuation of the protection by the added field current power is prevented. However, another automation system has already acted in this case: the automatic frequency load relief (AChR).

After the restoration of the 110 KV line power as a result of automatic reclosure action at the supply substation, the synchronous motors are automatically started sequentially. No protection against field winding feed is needed for asynchronous motors. When a power transmission line is disconnected, the asynchronous motors of final pumping stations and oil repumping stations are disconnected by the minimal voltage protection with a time delay of 0.5 to 1 second, something which is necessary because of production process considerations. The asynchronous motors of group pumping stations and water intake pumping stations can operate in an autostart mode. The minimal voltage protection for motors set aside for operation in an autostart mode has a time delay of from 15 seconds to three minutes, i.e., during this entire time, the switches for these motors remain closed, regardless of the presence of voltage on the 6 KV buses. The number of motors which are started simultaneously when power is restored is limited by the capacity of transformers and the power system.

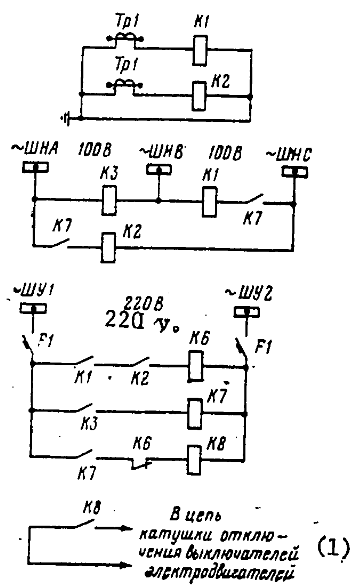

Figure 51. Basic schematic showing the protection against providing power to a short circuit point.

Key: 1. To the circuit of the disconnect coil for the electric motor switches.

Automatic reclosure for 35 KV lines is also used to restore the power of a 35 KV network in the case of non-selective action of the maximal current protection. A 35 KV ring network, consisting of single circuit open wire lines, is used in the case where there is the possibility of powering it from two sources: two 110/35/6 KV substations. The circuit for automatic standby switching action is shown in Figure 52. In all, there are eight 35 KV series connected switches (B1-B8) in the circuit (when powered from one side). The maximal current protection has a time delay of four seconds (counting 0.5 seconds for each switch). Because of the time delay which is impermissibly long based on considerations of system stability, this protection stage with selective disconnection of damaged transmission line sections is used only as standby protection. The primary protection is the first stage of maximal current protection, which has the same time delay of 0.5 seconds for all switches, with the exception of B1 and B9. The latter have a time delay of one second. In the case of a short circuit at any point in the grid, there is nonselective disconnection of all (or some) of switches B2-B4 or B6-B8. The restoration of the 35 KV network power with isolation of the damaged transmission line section is accomplished by the sequential automatic reclosure of the transmission line sections. Automatic reclosure of each successive transmission line between two 35 KV substations takes place only following the restoration of the voltage on the preceding power transmission line section.

During the automatic reclosure time, accelerated primary protection is introduced, i.e., in the case of the failure of the automatic reclosure to activate any transmission line section, the damaged section is disconnected without a time delay, and in this case, the major portion of the line previously connected by the actions of a successful automatic reclosure remains in service.

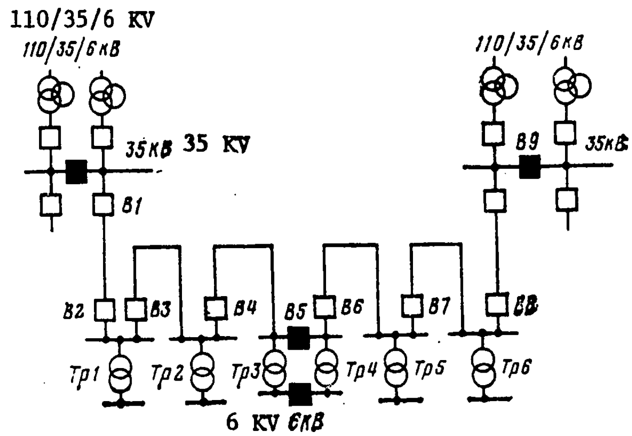

Figure 52. Schematic illustrating the action of automatic standby switching.

Key: B1-B9 are the switches;
Tp1-Tp6 are the power transformers.

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